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(6) SLEEP LOSS EFFECTS ON CONTINUOUS SUSTAINED PERFORMANCE

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The ability to sustain continuous performance for up to 42 hours was studied. During each 10 minutes, subjects performed a tracking task, a pattern memory task, an addition task, a simultaneous auditory vigilance task, and provided subjective ratings on sleepiness and attention-fantasy scales. Of 10 subjects required to work continuously with no breaks, 3 could not complete the 42 hours, and 8 out of 10 suffered symptoms such as hallucinations, visual illusions, and disorientation. Subjects provided either 6 one-hour naps


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or one 6-hour sleep period were able to complete the 42-hour study and suffered fewer psychiatric symptoms. The group working continuously suffered marked impairments of performance, especially in the addition task, while those receiving one-hour or six-hour rest periods sustained their level of performance much more effectively. These results show that when absolutely continuous sustained work is required, performance deteriorates seriously even within the first 24 hours.

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## INTRODUCTION

Previous studies of sleep deprivation have emphasized the duration of sleep loss required to produce measurable or severe impairments of performance. In most of these studies, performance in a variety of psychological tests was measured only intermittently, so that although the subjects were kept awake continuously, they had long rest periods when nothing specific was required of them.

In this study, we examined the impairments of performance which occur when subjects are required to work continuously with only negligible opportunities for rest and recuperation. A requirement for absolutely continuous performance is increasingly found in the tasks of modern life such as long distance driving, flying airplanes, monitoring radar screens, and similar assignments requiring continuous monitoring of electronic consoles or machinery.

Previous studies of sleep deprivation have suggested that the tasks most vulnerable to fatigue and sleep deprivation are those which are work-paced rather than self-paced, high workload, complex, requiring continuous attention and performance, and which are relatively monotonous (Naitoh, 1969; Johnson and Naitoh, 1974; Woodward, 1974). Immediate feedback tends to sustain performance (Wilkinson, 1961). Vigilance seems to suffer sooner than memory or cognitive skills (Naitoh, 1969).

Two mechanisms may impair performance early after minimal sleep deprivation (Kjellberg, 1977a, 1977b, 1977c). The first mechanism is the occurrence of lapses of vigilance, often associated with loss of EEG alpha. Williams, Lubin and Goodnow (1959) showed that a loss of alpha rhythm was closely associated with performance failure. A second mechanism may be a failure of attentional focus (Kjellberg, 1977b). Tests which require continuously focused attention may be differentially impaired, particularly beyond the first 10 minutes of task performance (Hockey, 1977a). High arousal increases the selectivity of attentional focus and may thus actually restrict attention to low priority tasks in a complex performance model (Hockey, 1977a, 1977b).

We believe that many of the sleep deprivation studies thus far reported may model continuous sustained performance poorly, because the performance tasks tested were relatively brief, and long breaks were allowed between testing sessions. Studies of physiologic effects of sleep deprivation have emphasized deprivations of 60-100 hours or more (Johnson, 1969). The continuous performances tested were continuous on a scale of days but not on a scale of hours.

The crucial factor in measuring the performance impairments which occur early seems to be the duration of the testing session (Wilkinson, 1969). Wilkinson, Edwards, and Hainer (1966) stated:

> "...if the duration of performance testing is extended so that it approximates to a normal day's work, the reduction of sleep by about half on a single night can produce a significant fall in working

efficiency. The reason why previous experiments...have failed to show this effect of partial sleep deprivation is almost certainly that the performance tests were too short. The complete loss of one night's sleep has no effect upon the first five min of work on serial reaction tests, vigilance and adding, but a clear impairment of performance emerges when these tests are prolonged for 15 to 40 minutes...."

This would suggest that breaks are crucial in sustaining performance on continuous high workload tasks. Perhaps the importance of breaks may help to explain the relatively favorable results obtained by Alluisi and colleagues with 4-on-4-off and 4-on-2-off schedules as opposed to 12-on-12-off, since one would certainly anticipate that subjects would obtain more sleep with 12-on-12-off schedules (Alluisi, 1972). The low-demand intervals in Alluisi's 2-hour performance modules may also have served as breaks. Similarly, breaks may provide a benefit favoring persistance of 4-on-4-off schedules in certain Naval settings, particularly aboard submarines.

With a view to exploring these issues further, we have designed and tested a model where subjects are required to perform virtually without any break or rest for up to 42 hours. The pressure of the performance tasks is continuous, and the motivation is high. Impairments of performance in this model were compared with impairments produced when a similar 42-hour work schedule was interrupted by several 1-hour breaks or by one prolonged 6-hour sleep period. The results tend to confirm our hypotheses that performance impairments appear very quickly when tasks must be sustained absolutely continuously without breaks. Both brief breaks and a longer rest period were very helpful in sustaining performance.

## METHODS

### Subjects

Subjects in the study were 32 male volunteers, mostly university students, recruited from advertisements in the campus newspaper. Ages ranged from 18 to 31 with a mean age of 21.4 years.

Potential subjects were screened by interview for suitability and for motivation to do well in the study. All subjects completed written informed consent forms on a day prior to the experiment.

### Protocols

On a day prior to the study, subjects were given instruction and were invited to practice the performance tasks for 30-40 minutes, so that they would be familiar with the procedures. They were told that even though they were free to drop out of the study at any time, we preferred that they complete the protocol and attempt to maintain a sustained high level of performance at all times. Subjects were paid $2 per hour for each hour of participation. In addition, in order to enhance motivation and compliance, subjects were paid up to an additional $2 per hour depending on their performance and contingent upon their completion of the study.

Approximately one hour prior to their normal bedtimes, subjects came to the laboratory to be equipped for polygraphic recordings. Right and left hemisphere parieto-occipital EEG, submental electromyogram (EMG), bipolar horizontal electro-oculogram (EOG), and activity from the dominant wrist were recorded during both wakefullness and sleep throughout the 48 hours of the study. Signals from an artifact detector attached to a head-mounted EEG preamplifier were recorded to aid in scoring EEG activity. (Polygraphic results will be described elsewhere.) Each study began with a 6-hour sleep period from the time of "lights out," which was chosen as the subject's usual bedtime. Subjects were then awakened (usually between 0500 and 0600, mean time=0510) and immediately required to commence performance testing.

Ten subjects were randomly assigned to each of three groups. A structured random assignment method was used so that each subject had an equal chance of assignment to each group, and the three protocols were run simultaneously from February through December of 1980, counterbalancing any order effects. One subject, who quit the study after only 3 hours of testing, was replaced. A second experiment was terminated by the experimenters when it was realized that performance data were not being stored due to an equipment failure, and this subject was also replaced.

In the first group (42-straight), subjects were required to maintain continuous performance for the final 42 hours of the experiment, from approximately 0500 of the first day to 2300 of the second day. In the second group (6-and-1), subjects were required to work continuously except that every 7 hours they were given a one-hour rest period, during which they were asked to sleep in bed with the lights out. In the third group (18-and-6), subjects were required to work continuously for 18 hours, then they were allowed a 6-hour sleep period, and finally a second 18-hour continuous performance period was required. Thus, within the 42 hours following the initial 6-hour sleep period, the total durations of the rest periods were equivalent in the 6-and-1 and the 18-and-6 groups. In the 6-and-1 group, however, the final 1-hour nap occurred after all performance testing was completed. Sequences of sleep periods and testing for all 3 groups are diagrammed in Fig 1.

Subjects worked alone in a well-lighted attractive 3x3.5m room, but they were intermittently visited by research staff to attend to subjects' needs and to repair occasional equipment problems. Subjects did not wear wrist watches, but they were not otherwise isolated from time cues such as hallway noises and a hallway clock. Subjects were permitted to walk across the corridor to use the restroom. Snack food and non-caffeinated beverages stored in a small refrigerator were available ad lib, but the performance tests were not discontinued for eating, drinking, or restroom trips.

Tasks

An Apple II microcomuter system was employed to present the performance tasks, to regulate the timing of the performance trials and sleep periods, and to store the data.

1. A 3-minute tracking task displayed a small randomly moving target on a

video monitor screen which also displayed a stationary grid. The subject's job was to position the target using a hand-held joystick (control stick) to the exact center of the grid, at which time pressing a "trigger" button could score a "hit" on the target. This task simulated electronically-controlled gunnery or missile firing. The subject was given immediate feedback of his performance, since the target would simulate explosion when properly tracked and hit. The number of "hits" was tabulated by the computer. This task was largely self-paced.

2. A visual pattern memory task was presented for 3 minutes. A randomly-generated 5X5 matrix of 25 squares (each either white or black) was displayed on the video monitor screen for 3 seconds. After this initial pattern disappeared from the screen, a second and a third pattern were sequentially displayed, either of which might be identical to the original pattern. The subject then indicated by pressing the appropriate key if the second, the third, or neither copy was identical to the first pattern. This task was totally experiment-paced; 3.2 seconds were allowed for response. Subjects received immediate feedback whether their identifications were correct or wrong.

3. A third 3-minute task tested numerical addition skills. The subject was required to add two randomly-generated 3-digit numbers (presented on the monitor), then add 7, and enter the 3-digit sum on a numeric keyboard. The time allowed for responses during the task was limited, and the limit was varied adaptively to create time pressure however performance varied. Thus, this task was experimenter-paced although adaptive to an individual's ability, and it tended to demand maximal performance speed. Subjects were also given immediate feedback regarding "correct" and "wrong" additions.

4. In experiments with 23 of our subjects, a fourth task, an auditory vigilance (AV) task, was required simultaneously with the first 3 tasks for 9 minutes. For the other 7 subjects, the technology was not functional. This task was an adaptation of the Wilkinson Auditory Vigilance Task (Wilkinson, 1969). In our AV task, long (520 msec) and short (160 msec) tones were presented every 3 seconds. Ten percent of all tones were short. Short tones were randomly dispersed among the long tones. Subjects were required to identify the short tones by pressing a foot pedal which registered both correct and incorrect identifications. This task was experimenter-paced, and there was no immediate feedback on performance.

During performance testing periods, subjects performed the tracking task, the pattern memory task, and the addition task each for 3 minutes. At the end of each task, the video monitor displayed summary feedback on performance in the form of a statement of the amount of bonus money earned during the 3-minute task interval. Thus, the performance tests were framed as a repetitive series of tasks where favorable performance was rewarded by money. The scoring system severely penalized failures to respond to the task presentations, so that inattention or sleep were heavily penalized, whereas errors representing continuing effort were less heavily penalized. In this way, the reward system was able to elicit very determined and motivated effort from almost all subjects.

At the end of each 9 minutes, a 100 mm vertical line was displayed on the left-hand side of the monitor screen. Seven areas along this continuum were associated with items of the Stanford Sleepiness Scale, which was presented adjacent to the line (Table I). Subjects were instructed to use the joystick to quantify their subjective sleepiness or alertness on this continuous self-report scale. Next, a similar linear scale was displayed on the right of the screen to register a subjective self-report on a continuum scale ranging from complete attention to intense fantasy or daydreaming (Table II). Subjects then indicated how much they had eaten or had had to drink and whether they had used the restroom during the prior 10 minutes. Food items (sandwiches, fruit, etc) were assigned semi-quantitative numeric values by the experimenters (eg, one-fourth sandwich = 2), and drinks were quantified as the number of 3-ounce cupfuls. Subjects used a numeric keyboard to indicate the units of food and drink consumed over the last ten minutes. After this information was provided, the computer program then presented AV task performance feedback along with summary performance feedback on the total amount of money earned over the past ten minutes. The program also displayed a projected hourly rate reflecting performance levels during the past 10-minute module. Since in practice, most subjects were able to respond to all self-report items quickly within 15-20 seconds, they were afforded about 40-45 seconds to rest, obtain food from the refrigerator, or visit the restroom before the tasks were again resumed. If subjects were not ready to resume their duties at the end of this 40-45 seconds, they were penalized by the system for failures to respond. This sequence repeated itself every 10 minutes throughout the periods of performance testing, resulting in 6 scores per hour for each performance task and each subjective measurement.

Follow-up

At the conclusion of the study, while electrodes were being removed, subjects were interviewed and asked to complete a brief questionnaire. Subjects were then driven home unless they preferred to walk to nearby on-campus housing. Telephone follow-up contacts were made the next day with subjects who had experienced any physical or psychological difficulties in the course of the study, in order to assure the subjects' health. Later follow-ups were also obtained from time to time.

## RESULTS

### Compliance and Psychiatric Symptoms

A major finding was that almost all of the subjects in the three 42-hour protocols completed the studies. Two subjects who were recruited did not finish and were not included in the data analyses. One of these subjects, who was assigned to the 6-and-1 group, quit after only 3 hours of continuous performance. This subject expressed a surprising lack of motivation, which became apparent after one and one-half hours of testing, when his performance deteriorated. A second 42-straight study was terminated by the experimenters due to an equipment failure. Experimental group assignment was not considered a significant factor in the termination of these two studies, so these two subjects were replaced to complete the experimental design.

Three additional subjects, all in the 42-straight group, also dropped out of the study after 17, 26, and 40.5 hours of continuous performance. Since these 3 had all been randomly assigned to the 42-straight group and were all well-motivated subjects, these failures were interpreted as experimental effects. These dropouts reduce the numbers of subjects included in the 42-straight group statistical analyses for the latter part of the 42 hours.

Although the other 27 subjects were all able to complete the protocol, many reported minor physical discomforts and psychological impairments or disturbances. Examples of verbatim subjective reports are given in Table III. As is shown in Table IV, about half of all subjects reported some mild hallucinations, visual illusions, or experiences of derealization and depersonalization. Eight of 10 subjects in the 42-straight group experienced one or more of these psychiatric symptoms. Subjects in this group experienced significantly more of these symptoms than subjects in the other 2 groups (Table IV). Only 2 subjects in the 18-and-6 group reported such disturbances, and these were only mild visual illusions. Four subjects in the 6-and-1 group experienced mental symptoms including hallucinations. It is apparent that rest breaks were effective in minimizing psychiatric symptoms, and the 6-hour break was more effective than the 1-hour breaks. Several subjects also mentioned somatic complaints such as nausea, headache, backache, etc, some of which were very likely psychosomatic in origin. The majority of these complaints also occurred in the 42-straight group.

## Performance Data and Subjective Measures

Examples of performance scores for typical individual subjects appear in Fig 2. In order to provide comprehensive analyses of these data, hourly group means were plotted with confidence limits for each group separately see (eg, Fig 3). In addition, the hourly means were plotted without confidence limits for all three groups on the same axes. To emphasize intra-subject variations in performance over time while minimizing the contributions of inter-subject variability, the separate 10-minute scores for each subject were normalized (converted to z-scores) by subtracting the mean and dividing by the intra-subject standard deviation. Then normalized group means and confidence limits also were derived. These normalized data were then replotted. Improvement or deterioration in these z-normalized plots can be interpreted by appreciating the changes in z-normalized performance after the start of the study. A final plot was prepared to facilitate comparison of the 3 groups. Normalized scores from each group were plotted on the same axes, adjusting the scores so that for each group, the mean z-score for the initial 6 hours was placed at the 0-level of the ordinate. Assuming that random assignment produced groups initially equated during the first 6 hours of performance (before the three protocols diverged), these latter plots present the most cogent demonstrations of the divergences between experimental groups. Plots of normalized mean data were generally similar to non-normalized mean plots, but it will be seen that the normalized plots give a more precise description of change with narrower confidence regions. Results for each measure will be described separately.

<u>Tracking.</u> In the tracking task, there was a clear and consistent

divergence in the performance of the three groups during the 42 hours of the study (Fig 3). All three groups improved their performance steadily during the first 18 hours of performance, presumably because of a learning effect, although a time-of-day effect could not be excluded. Early improvement was greatest in the 6-and-1 group which seemed to benefit from the one-hour naps. From 18 to about 28 hours after the beginning of performance testing, that is, from approximately 2300 at night until 0900 the next morning, there was a progressive deterioration in the performance of all three groups, due to a time-of-day effect or 24-hour rhythm. Both the 18-and-6 and the 6-and-1 groups then showed continuing improvements in performance later in the second day, but the 42-straight group showed continuing deterioration due to fatigue. The 18-and-6 group showed superior performance throughout the second day, indicating that the one 6-hour sleep period preserved performance better than the five 1-hour naps. It is interesting that the tracking performance of all groups was always worse in the first hour after awakening than during immediately subsequent hours. On four or five occasions, tracking performance was worse in the 6-and-1 group in the first hour after a nap than in the last hour before the nap. Performance was also poorer in the 18-and-6 group in the first hour after the 6-hour sleep period than during any hour of the 6 hours preceeding the sleep period. This waking-up effect was in part due to the fact that the performance tasks began immediately at the end of the sleep period, and subjects required some time to move from the bed to the computer console to begin work. Nevertheless, since decrements in performance were sometimes seen for several 10-minute testing epochs, this waking-up effect was not due to mechanical problems in getting started alone.

Pattern Memory. A slight trend for pattern memory to improve was seen in all three groups in the first 18 hours (Fig 4). There was particular improvement in the 6-and-1 group, an apparent benefit of their naps. All three groups showed some decrement from about 16 to 26 hours after the start of performance, due to a 24-hour rhythm or to time-of-day. The dip was particularly pronounced in the 42-straight group. Performance was markedly improved in the 18-and-6 group after the rest period, and even the 42-straight group showed some improvement toward the middle of the second day, before further deterioration appeared. On all occasions, performance was worse in the first hour after awakening than in subsequent hours, suggesting a waking-up effect. Poor performance in pattern memory after waking up was seen almost entirely in the first 10 minutes after a rest period, so it could have been produced largely by difficulty in getting seated at the computer console, especially since "no answer" responses were most frequent at this time.

Failures in the pattern memory task were produced both by incorrect responses and by failures to respond within the 2-second time limit. Fig 5, a graph of "no answer" responses to the pattern memory task, shows that the 42-straight and 6-and-1 groups failed to respond much more commonly during the second day of performance, and the 6-and-1 group had many failures to respond in the first hours after awakening from rest periods. More failures to respond also occurred in the 18-and-6 group following the 6-hour sleep period than at any other time for that group. Failures to respond were always most common in the first hour after awakenings from rest periods.

Addition. After a rapid improvement in the first four or five hours, attributed to learning, addition performance deteriorated in both the 42-straight and the 18-and-6 groups (Fig 6). It was interesting that the subjects' addition skills substantially improved in the first 18 hours in the 6-and-1 group, indicating that the benefit of learning was greater or the fatigue was less in these subjects because they received brief rest periods. Nevertheless, both the 42-straight and the 6-and-1 groups deteriorated markedly during the first night from about 20 to 28 hours after beginning work, that is, from about 0100 to 0900. Mild recovery of performance occurred towards noon of the second day in these groups followed by further deterioration. The 18-and-6 group improved markedly after the 6-hour rest period before deteriorating later during the second day. Although the relative improvement of performance during the second day for the 18-and-6 group was extremely impressive, the absolute performance of this group during the second day was not consistently superior to the 6-and-1 group (Fig 6). This was most probably because the absolute performance in the addition task was consistently and significantly poorer for the 18-and-6 group during the first day compared to that of the other two groups. We have no explanation why the absolute performance of the three groups was not equivalent at the start of the study. The deterioration in addition of the 42-straight group was particularly impressive, as these subjects were able to perform less than half as many correct additions at the end of 42 hours of continuous work as they were able to do at the beginning of the study.

In all three groups, there was a slight trend for the numbers of incorrect addition responses to decrease as the study progressed (Fig 7). "Incorrect additions" included both erroneous answers plus instances where subjects failed to answer within the allotted time. This result therefore suggests that deteriorations of correct addition completions were due to loss of speed rather than to errors of accuracy. Trends in the "no answer" responses to the addition task, measured separately, were not large or consistent (Fig 8). Thus, the trends in the "no answer" responses were also consistent with the interpretation that the reduction in addition performance was largely due to a loss of speed.

Addition performance was always worse in the first hour after rest periods. Because this effect usually persisted 30 minutes or more after awakenings and was more noticeable in correct and incorrect responses than in "no-answer" scores, it appeared to be due to impairments of speed and not due to mechanical problems in becoming seated at the console.

Auditory Vigilance Task. Correct responses in the auditory vigilance (AV) task were approximately stable throughout most of the first 18 hours of the study for the 42-straight and the 18-and-6 groups although responses were more variable in the 18-and-6 group (Fig 4). In the 42-straight group, performance began to deteriorate during the early evening. Absolute level of performance in the 18-and-6 group were almost identical to those of the 42-straight group during this time. In contrast, the 6-and-1 group demonstrated a possible learning effect over the first 6 hours and then maintained relatively improved performance during the rethen mainder of the first 18-20 hours. This again suggests a possible benefit of the 1-hour rest breaks in the first half of the performance testing period. As the study progressed, a definite deterioration in AV correct responses occurred in the 42-straight and the 6-and-1 groups between 18 and 24 hours after the beginning of the study. After 24 hours, AV performance stabilized in the 42-straight group -- the rapid deterioration plotted in the final 5 hours may not be significant. In contrast, performance in the 6-and-1 group was improved after the trough at about 24 hours. AV performance in the 18-and-6 group was fairly stable during the final 18 hours of testing and was at an almost identical level as during the first 18 hours.

False responses in the AV task which were previously occurring at a stable level increased steadily after 20-22 hours in the 42-straight group (Fig 10). False AV responses were fairly stable in the 18-and-6 group during both 18-hour test periods except for a brief 3 to 4 hour decrease after the 6-hour rest. False responses in the 6-and-1 group increased after 21 hours. This slight increase in AV false responses in the 6-and-1 group was trivial compared to the much larger increase which occurred in the 42-straight group during the last half of performance testing. The significance of false responses in the 42-straight group was increased by the fact that this group made fewer false responses at the beginning of the study compared to the other two groups.

Sleepiness. Subjective sleepiness scores increased substantially in all three groups during the first 18 hours of the study (Fig 11). The range of the increase was from approximately "Functioning at a high level, but not at peak; able to concentrate" to "Sleepy; woozy; prefer to be lying down; fighting sleep" on the Stanford Sleepiness Scale. It is interesting that during the first 18 hours, even though the 6-and-1 group indicated somewhat greater subjective sleepiness during the first 6 hours compared to the other groups, 6-and-1 subjects reported less sleepiness over the remainder of the first 18 hours. This was apparently due to the benefit of the brief naps. Compared to the 42-straight group, increases in sleepiness as the study continued were much less in the 6-and-1 group, also suggesting that the brief naps attenuated sleepiness. A very distinct peak in sleepiness occurred in the 42-straight and 6-and-1 groups 24-25 hours after the beginning of the study, that is, at 0500-0600 AM of the second day, and sleepiness actually decreased during the course of the second day of performance. The increase in sleepiness in the early morning hours indicates that time-of-day or 24-hour rhythm effects were stronger than the effects of progressive fatigue in modulating sleepiness. The reported sleepiness of the 18-and-6 group was less than that of the 6-and-1 group throughout most of the second day, but this benefit was lost toward the end of the second day when the total duration of the rest periods for the two groups became roughly equivalent. In every instance, the sleepiness reported in the first hour after awakening was greater than that in the following hour. Increased sleepiness was prominent up to 20-40 minutes after awakening. As might be expected, the sleepiness of the 42-straight group was markedly greater in the second day than that of the two groups which received rest periods.

Attention-Fantasy Scale. In general, the trends in the attention-fantasy scale were the reciprocal of trends in sleepiness, that is, at times when subjects reported increased sleepiness, less attention to the external environment and greater fantasy or daydreaming were reported (Fig 12). The only exception to this observation was that subjects always reported more sleepiness in the first hour after arousal, and they usually reported less attention (more fantasy) during this hour. There were some occasions when subjects reported more attention in the first hour after arousal than in subsequent hours. The range of the mean reports was from "awareness of present surroundings, thinking of what is happening" to "abstract and fanciful thinking, especially past and future".

Food Consumption. There was a slight tendency for subjects in all three groups to report less frequent food consumption as the study progressed, nevertheless, the trends were not strong compared to the large variability in the timing of eating (Fig 13). There was a definite trend for subjects to eat in the first hour or two after a rest period than in subsequent hours. This trend was not as prominent in the first 10-20 minutes after awakening as later in the hour.

Drinking. As with consuming food, there was a slight trend for subjects to drink less as the study progressed, but this trend was by no means prominent compared to the overall variability of drinking occurrences (Fig 14). There was no consistent trend for subjects to drink more in the first hour after awakening.

Restroom Trips. There was no definite trend over time in the numbers of restroom trips for any group (Fig 15). Nevertheless, restroom trips were more common in the first hour after rest periods, but not especially in the first 10-20 minutes.

## DISCUSSION

The design of this study was rather unique in that subjects were required to display almost continuous sustained performance for extended periods of time. It was gratifying that four separate performance variables plus the sleepiness and attention-fantasy scales all showed consistent trends.

In general, subjects had marked difficulty in sustaining truly continuous performance for 42 hours. Performance on all tasks deteriorated, and three subjects had to discontinue participation despite high motivation. Most subjects who worked without rest periods experienced psychiatric symptoms such as hallucinations, visual illusions, or sensations of derealization. Such symptoms appeared much earlier than had been reported in sleep-loss studies where only intermittent performance was required. Although our subjects were not explicitly isolated from external sensations, interpersonal communication with subjects was minimized to prevent distraction. Other sensory inputs were restricted by the attentional focus demanded by the performance tasks. We speculate that a narrowing of attentional focus onto monotonous, repetitive inputs led to these symptoms. Thus, without formally restricting the quantity or quality of sensory inputs and social contacts, continuous sustained performance may have effects much like those of sensory isolation (Zubek, 1969). In future research, we plan to further explore which factors are most instrumental in so quickly producing psychiatric disturbances.

Subjects permitted 6 hours of rest in 42 hours suffered much less deterioration. Even one-hour naps were beneficial even 6-13 hours from beginning work, however, single 6-hour rest period reduced impairment more overall, particularly during the second day of testing.

A mixture of factors was found to influence continuous sustained performance.

At the beginning of the performance testing portion of the experiment, all three groups showed some progressive improvements in several tasks. These improvements were very likely due both to learning and to time-of-day effects. Although the subjects had practiced the tasks for up to an hour prior to the day of the experiment, it would appear they had not yet reached asymptotal performance. There was a tendency for improvement of performance to occur from around 0500 to 0900 or 1000 in the second day of the experiment as well as in the first day, so time-of-day effects were also suggested.

Superimposed on learning effects, fatigue effects of varying strength supervened, so that improvements in performance related to learning were balanced by increasing fatigue. Effects of fatigue early in the experiment were demonstrated by the superior performances of the 6-and-1 group after the first and second rest periods. Since the 6-and-1 group showed more improvement than the other two groups in the first 18 hours of performance, it is evident that the brief rest periods were useful in counteracting fatigue after as little as 6 hours of continuous performance. There had been only minimal sleep deprivation before 18 hours of performance, since all subjects started from a 6-hour sleep period at their usual bedtime.

Approximately 18 hours after performance testing began (on average, about 2300), a new factor became manifest by an abrupt deterioration in performance in the 42-straight and 6-and-1 groups. It is evident that performance fell rapidly during the subjects' usual hours of sleep, after about 2300. This dip in performance lasted until about 0900 the next morning, when a partial recovery of performance appeared. Since 18-and-6 subjects were allowed to sleep during the night, their performance during night hours was not tested, but there was a striking improvement in performances of the 18-and-6 group after the 6-hour rest period. In the second day, the 18-and-6 group performed consistently better than both the 6-and-1 group as well as the 42-straight group. This may be either because the total amount of rest received by the 18-and-6 group before the second day (6 hours) exceeded that of the 6-and-1 group, or it may be that the more extended rest period was of more value than several shorter rest periods for sustaining performance. Another possibility is that rest during the normal hours of sleep was more valuable to the 18-and-6 group than rest periods scattered around the 24 hours for 6-and-1 subjects. There is some evidence that the total quantity of rest received was critical, since in several tasks, the performances of the 6-and-1 and 18-and-6 groups tended to approach each other toward the end of the second day. Nevertheless, even up until the final hours of the experiment, the 6-and-1 group had still received 1 hour less total sleep than the 18-and-6 group. This led to an unfortunate asymetry of design.

Rest periods had bi-phasic effects. In the first hour (and especially the first 10-30 minutes) after a rest period, performance tended to be actually somewhat worse and sleepiness somewhat increased compared to that prior to the rest period. On the other hand, in subsequent hours, the rest periods seemed to be of benefit for improving sustained continuous performance, and overall, the rest periods were of most definite benefit. Poor performances immediately after rest periods may to some extent have been due to distractions or mechanical factors. During the 10-minute modules immediately after rest periods, subjects may have been at a disadvantage because of the time required to move from the bed to the computer console and become settled for work. Subjects tended to consume more food, to drink more, and to visit the restroom more often in the first hour after rest periods. These activities may have kept the subjects away from the computer console during testing and may have provided a psychological distraction. Nevertheless, since impairments continued for several 10-minute modules after rest periods, and since increased subjective sleepiness was reported after rest periods, distractions and mechanical factors alone do not explain the results. We conclude that the rest periods did indeed produce a brief hangover effect which impaired performance.

From the reasonably reliable hour-to-hour consistency of these results and the relatively narrow confidence limits for mean performances for the three groups of subjects, we infer these results have considerable reliability for the particular experimental model which we have tested. The generalizability of the results to other schedules of performance demands, to other physical and social settings, or to other practical provisions for feeding and restroom visits is uncertain. Generalizability could only be definitely determined by varying the experimental designs.

As we had predicted, performance on the various tasks was affected somewhat differentially by the continuous sustained performance model. The tracking task showed some actual improvements over time in the 18-and-6 and 6-and-1 groups, whereas the deterioration of the 42-straight group was modest. This was to be expected since the tracking task required only brief periods of sustained attention, and performance could be largely self-paced. Performance in the pattern memory task also deteriorated relatively little in the 42-straight group, and there was some improvement in the 18-and-6 group over time. The relative success of subjects with this task may be related to the fact that the pacing, although experimentally controlled, involved little time pressure. In contrast, the addition task displayed a profound impairment in the 42-straight group, and the 6-and-1 group showed considerable impairment beyond 18 hours from the beginning of the study. The difficulties with sustained performance on this task may be related to its very high cognitive load, to its requirement for relatively extended concentration and memory, to the extreme time pressure, and to the fact that the timing (although adaptive) was entirely experiment-paced. Less specific and discrete changes were observed in the AV task than in the other tasks, although this task had proven particularly sensitive in former studies of sleep deprivation. The relative lack of sensitivity of this task in our experiment may have been related to the technical difficulties we experienced, lowering the numbers of subjects who were tested on this task in each group. The fact that this task was required simultaneously with the other performance tasks may also have been a factor. The most likely explanation is that the auditory vigilance task is not particularly sensitive to a sustained continuous performance model.

In summary, continuous sustained performance produced rapid fatigue effects which were measurable after only 6 hours of sustained performance, before sustained sleep deprivation could occur. Within a relatively brief period, less than 42 hours, rather serious decrements in performance occurred, and disturbing psychological symptoms such as visual illusions, hallucinations, derealizations and disorientation were reported. These aberrations in themselves may have interfered with task performance. Some well-motivated young men were quite unable to work for 42 hours continuously. Both 1-hour and 6-hour rest periods were effective in attenuating performance decrements. One hour rest periods were most valuable within the first 18 hours of sustained performance, but a 6-hour rest period was more useful than six 1-hour rest periods over a total performance interval of 42 hours.

These results indicate that impaired performance must be anticipated in personnel required to sustain continuous performance at electronic consoles much earlier than would be predicted from classic studies of sleep deprivation utilizing intermittent performance testing. Substantial performance deterioration should be anticipated after 18 hours of continuous performance. In addition, circadian rhythm or 24-hour time-of-day effects produce prominent early impairments of continuous performance. Subjects required to perform during their normal hours of sleep will show marked impairments even within the first 24 hours of sleep deprivation. Manning strategies should be adapted to anticipate these difficulties in any future conflict which would require continuous sustained performance of key personnel.

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TABLE 1. Stanford Sleepiness Scale Items

| |
|---|
| Almost in reverie; sleep onset soon; losing struggle to remain awake. |
| Sleepy; woozy; prefer to be lying down; fighting sleep. |
| Foggy; slowed down; beginning to lose interest in remaining awake. |
| A little foggy; let down; not at peak. |
| Relaxed; awake, responsive, but not at full alertness. |
| Functioning at a high level, but not at peak; able to concentrate. |
| Feeling active and vital; alert; wide awake. |

TABLE 2. Attention-Fantasy Scale Items

| |
|---|
| Present-time perceptual scanning and perceptual-motor activities. |
| Awareness of present surroundings, thinking of what is happening, etc. |
| Concrete, realistic, and present-time thinking or planning. |
| Abstract and fanciful thinking, especially past or future. |
| Vivid dreamlike fantasies with bizarre or symbolic content and strong emotions such as wishes or fears. |

Table 3: Examples of Psychiatric Disturbances

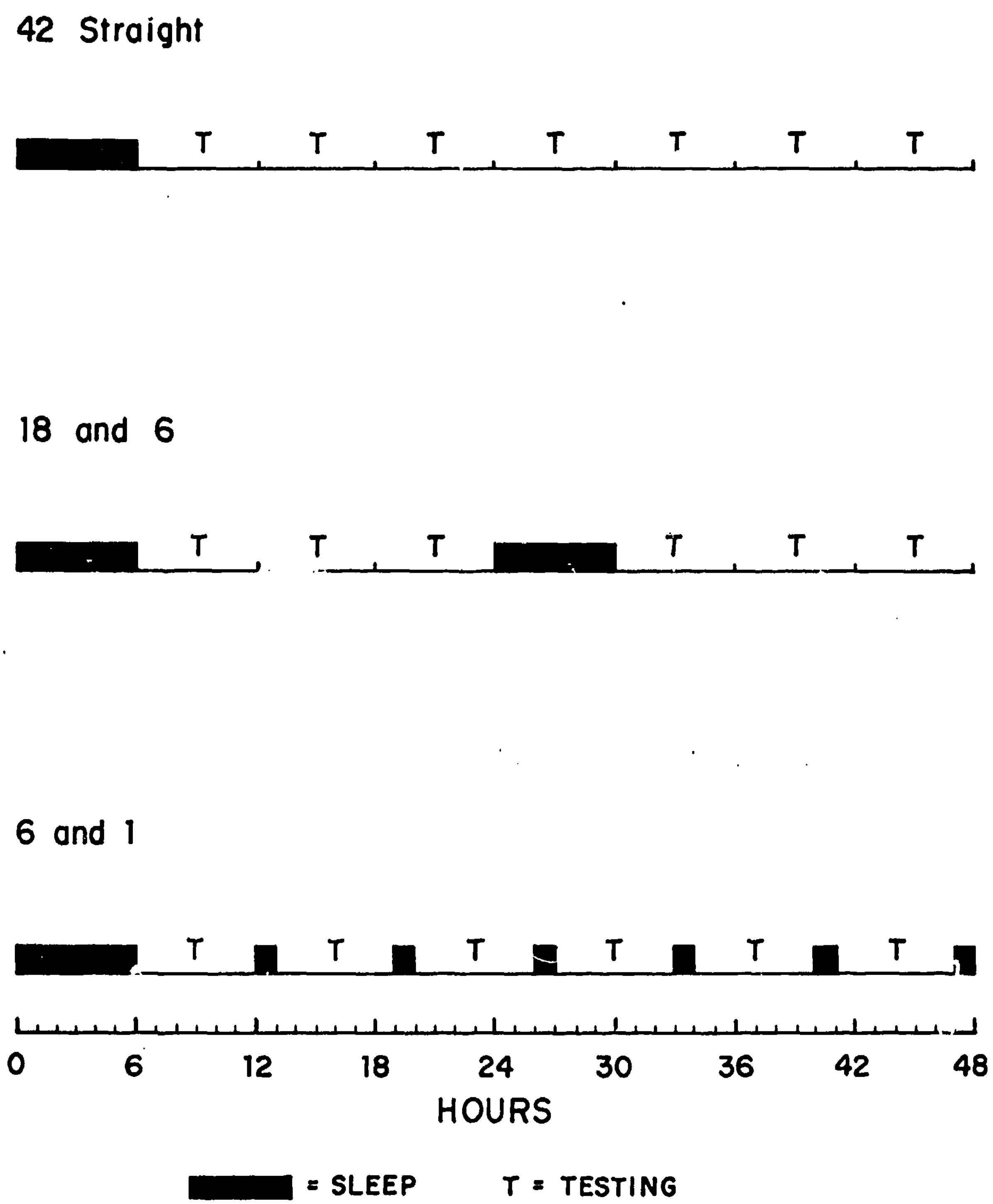
| Type of Example | Subjective Description |
| --- | --- |
| Visual Illusion | "....it looked like there was water starting underneath the seat flowing back towards the wall." |
| | "I would look at my jeans and see lots of red thread in them.And a kinda sheet of red in the paint...." |
| Disorientation | "....for a period of 2 hours, the whole room....I was never sure where the door was." |
| Derealization | "All of the objects were in the same place as the objects I was used to, but they looked different." |
| | "I thought I was at home doing this and my roomate would come in and I just wanted to say something to him and I realized he wasn't here." |
| Hypnagogic Hallucination | "I was just getting ready to go to sleep and all of a sudden I heard real low voices and someone talking about Earth....It was just nonsense." |
| Hallucination | "....it would look like someone was looking out of the screen, like it was a window....like there was someone behind there looking out." |
| | "I found myself trying to receive something from what I thought was a woman standing in front of me, while actually I was just grabbing at the card next to the TV set." |

TABLE 4: Psychiatric Disturbances During Performance Testing

| Group | Illusions and Distortions | Derealization and Disorientation | Hypnagogic Hallucinations | Hallucinations | Number of Subjects with any Symptoms |
|---|---|---|---|---|---|
| | Type of Disturbance | | | | |
| 42 | 7 | 5 | 1 | 3 | 8 |
| 18&6 | 2 | | | | 2 |
| 6&1 | 1 | | 2 | 2 | 4 |
| | | | | | Total =14 |

For the number of subjects with any symptom in the three groups, $X^2=7.49$, $p<0.025$

FIG 1. DIAGRAMMATIC ILLUSTRATION OF EXPERIMENTAL GROUP PROTOCOLS



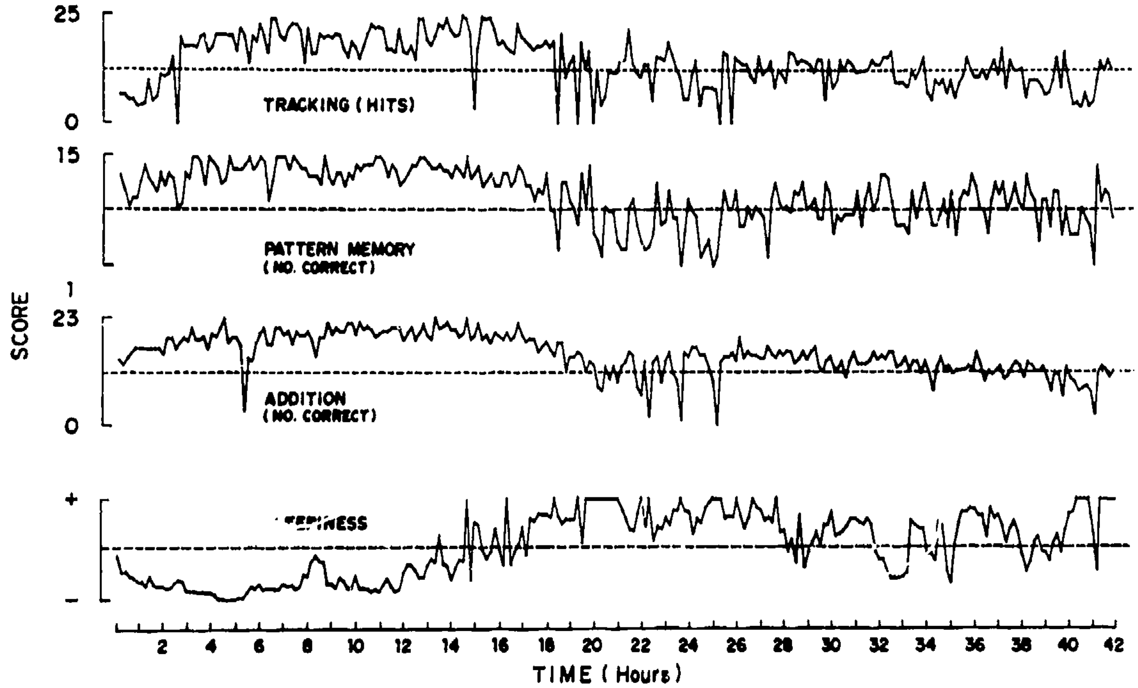



FIG. 2A Individual data points collected every 10 minutes for tracking, pattern memory, and addition performance plus subjective estimates of sleepiness. These data were obtained from a representative subject in the 42-straight group.

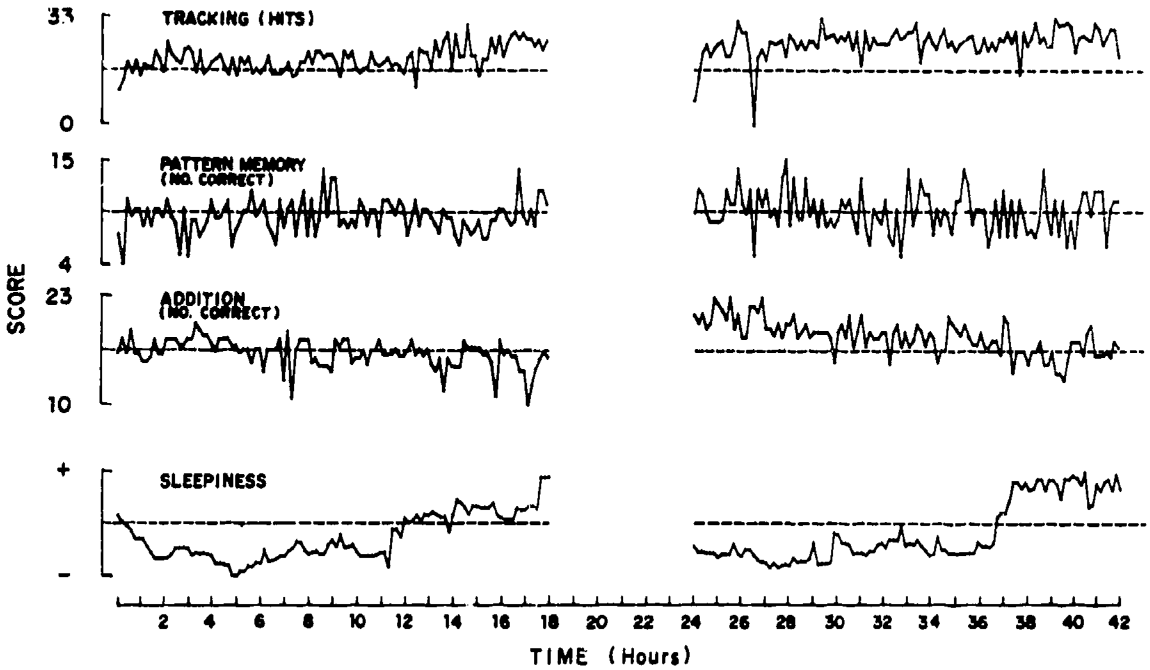



FIG. 2B Individual data points collected every 10 minutes for tracking, pattern memory, and addition performance plus subjective estimates of sleepiness. These data were obtained from a representative subject in the 18-and-6 group.

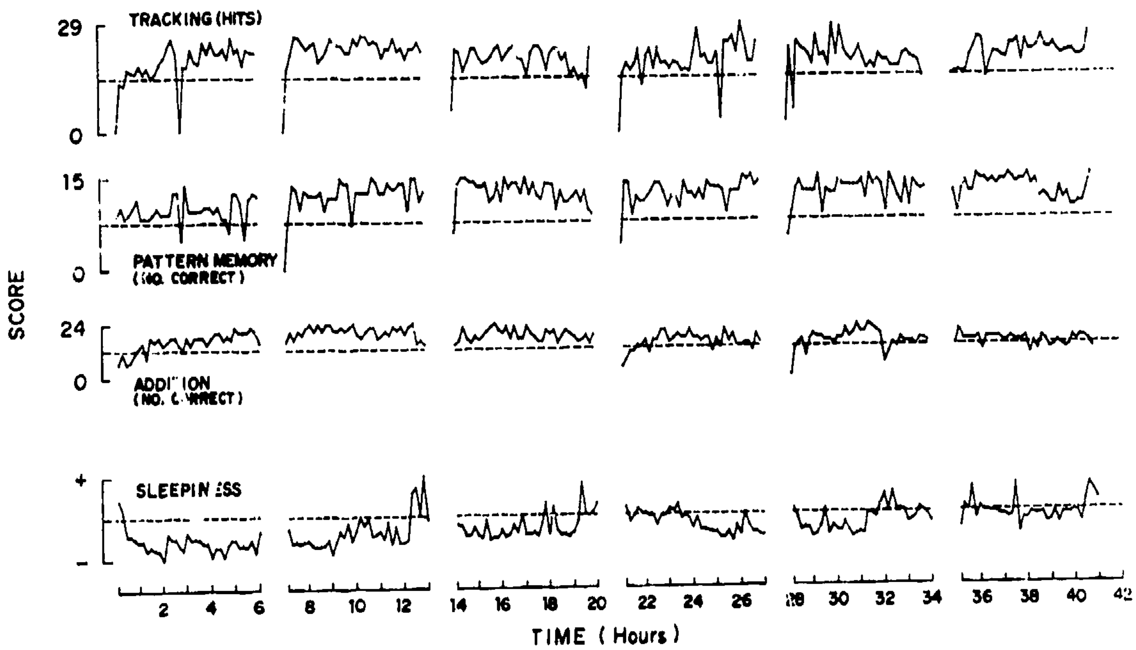



FIG. 2C Individual data points collected every 10 minutes for tracking, pattern memory, and addition performance plus subjective estimates of sleepiness. These data were obtained from a representative subject in the 6-and-1 group.

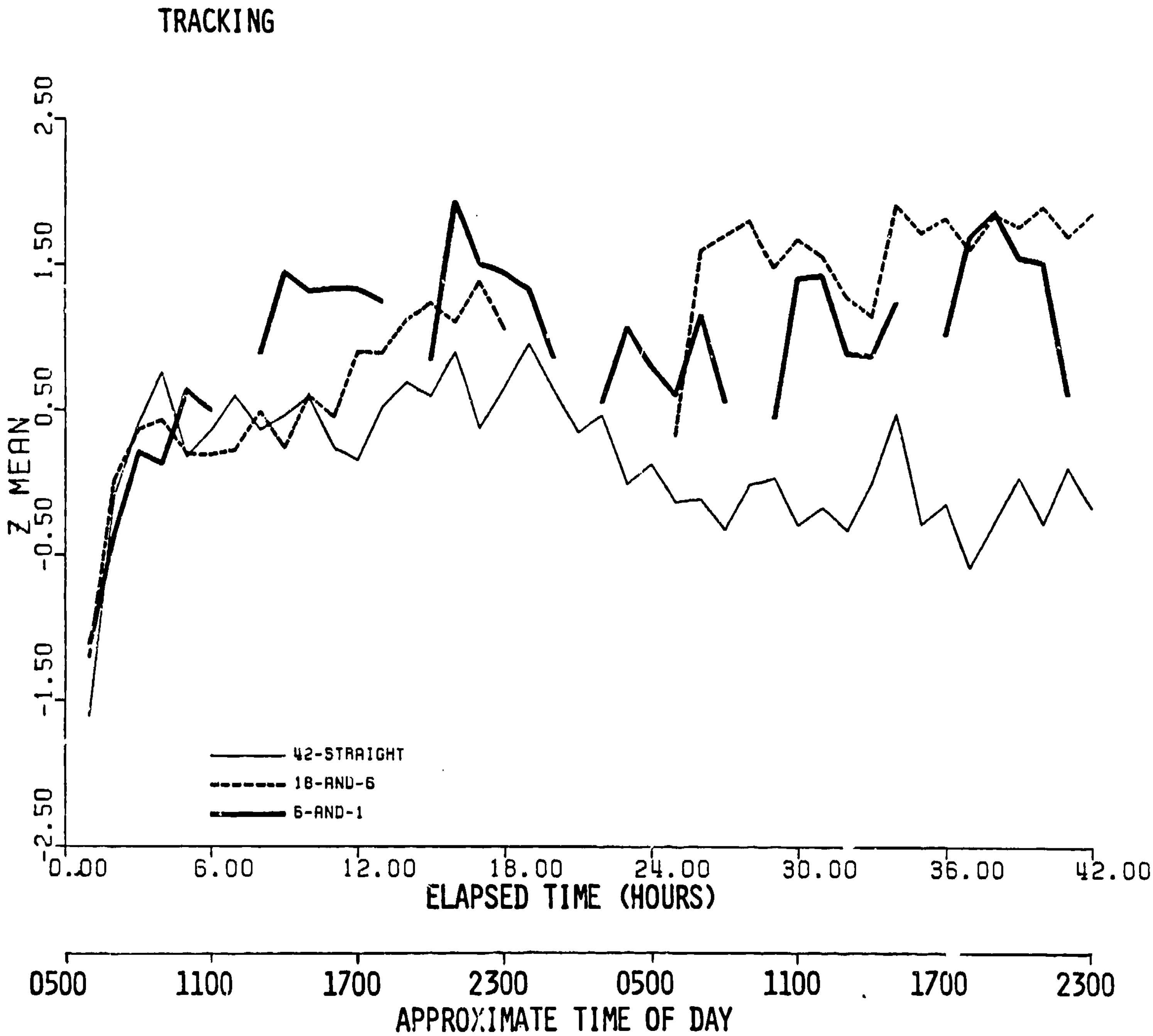



FIG. 3A Hourly means of normalized tracking performance for the three experimental groups. Group data are plotted with the mean z-score of the first 6 hours set to the 0 level on the ordinate. Means were derived from z-scores for the entire data of each subject.

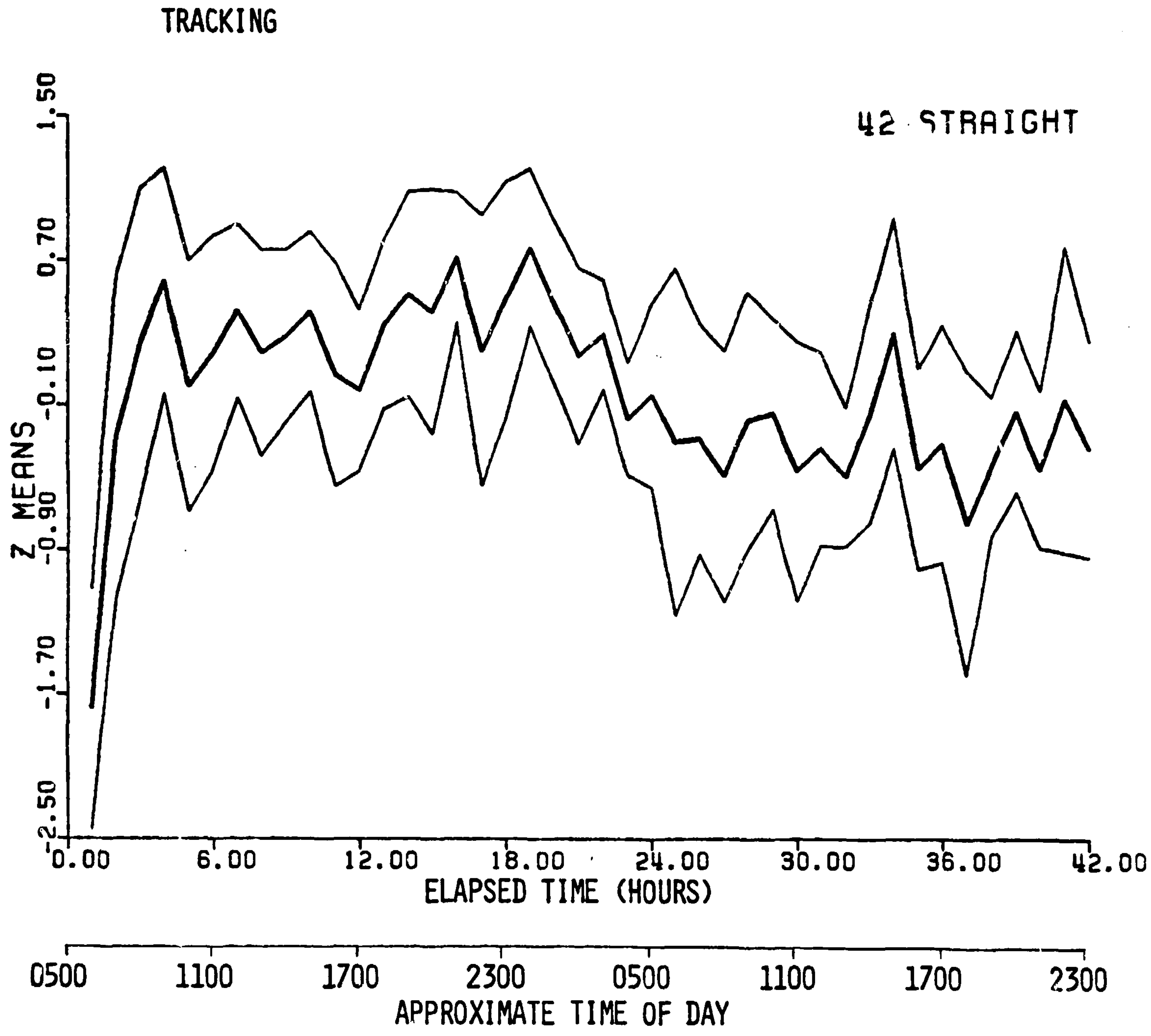



FIG. 3B Hourly means of normalized tracking performance for the 42-straight group. Means were derived from z-scores for the entire data of each subject. Also plotted are 95% confidence limits.

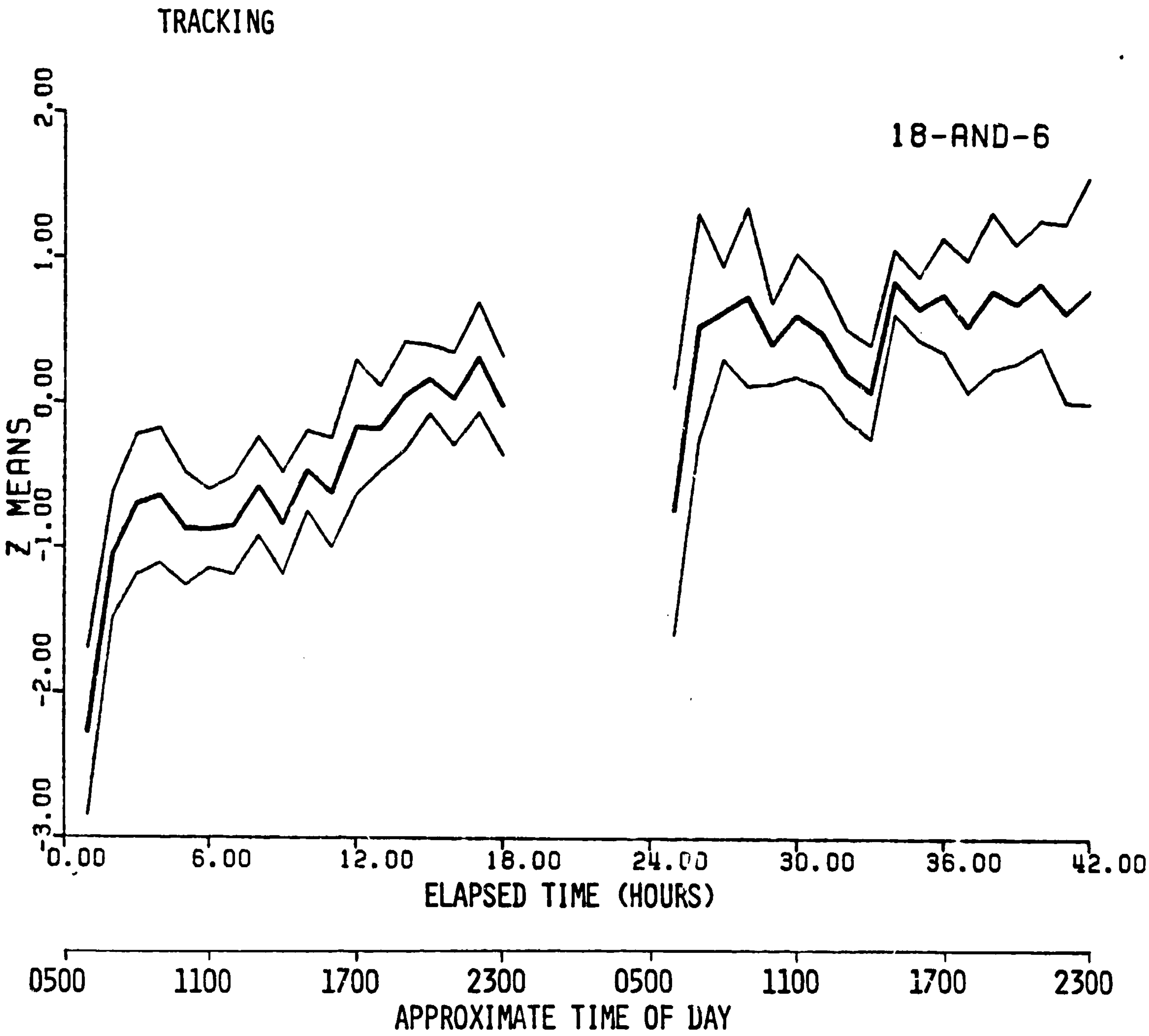



FIG. 3C Hourly means of normalized tracking performance for the 18-and-6 group. Means were derived from z-scores for the entire data of each subject. Also plotted are 95% confidence limits.

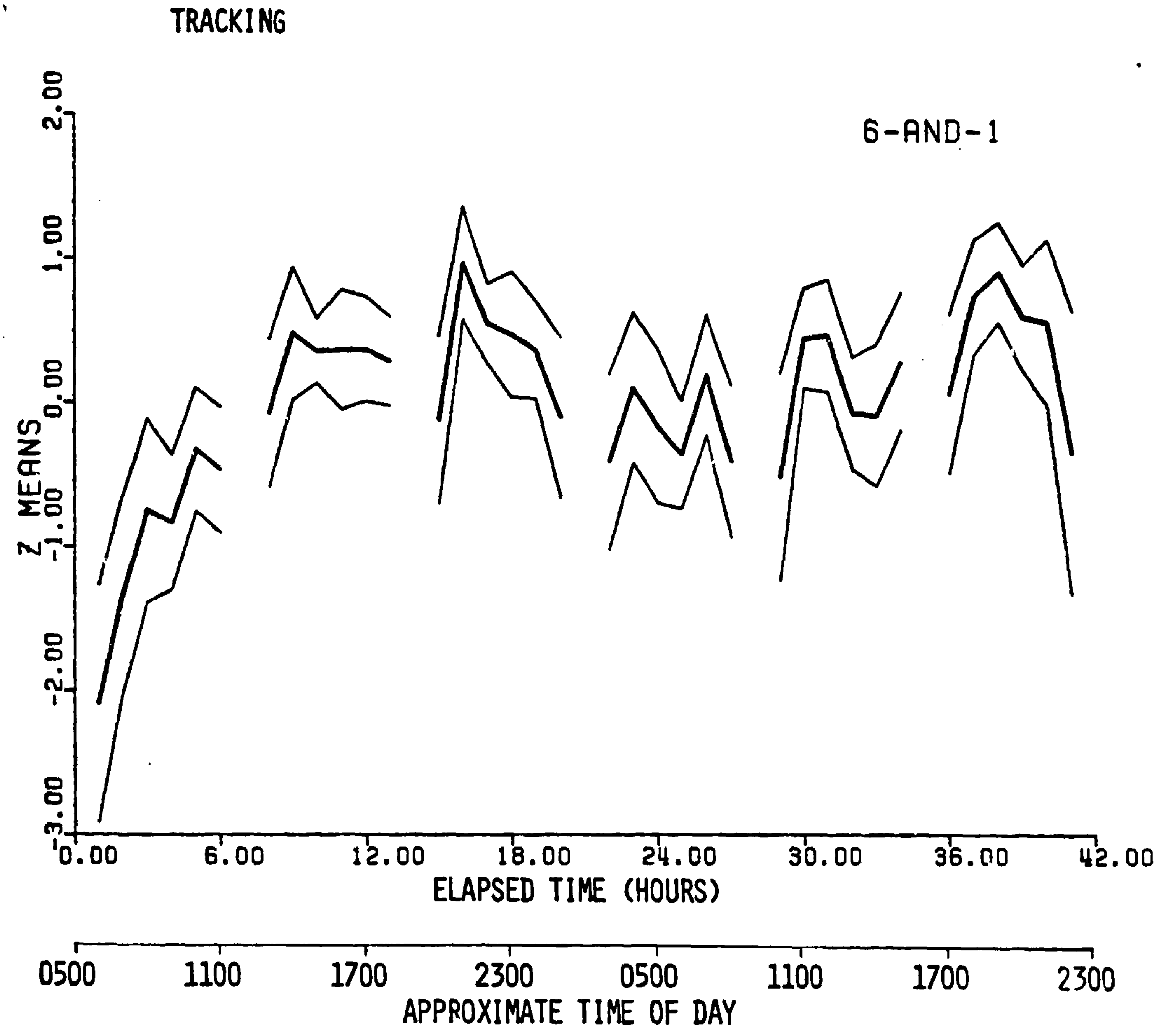



FIG. 3D Hourly means of normalized tracking performance for the 6-and-1 group. Means were derived from z-scores for the entire data of each subject. Also plotted are 95% confidence limits.

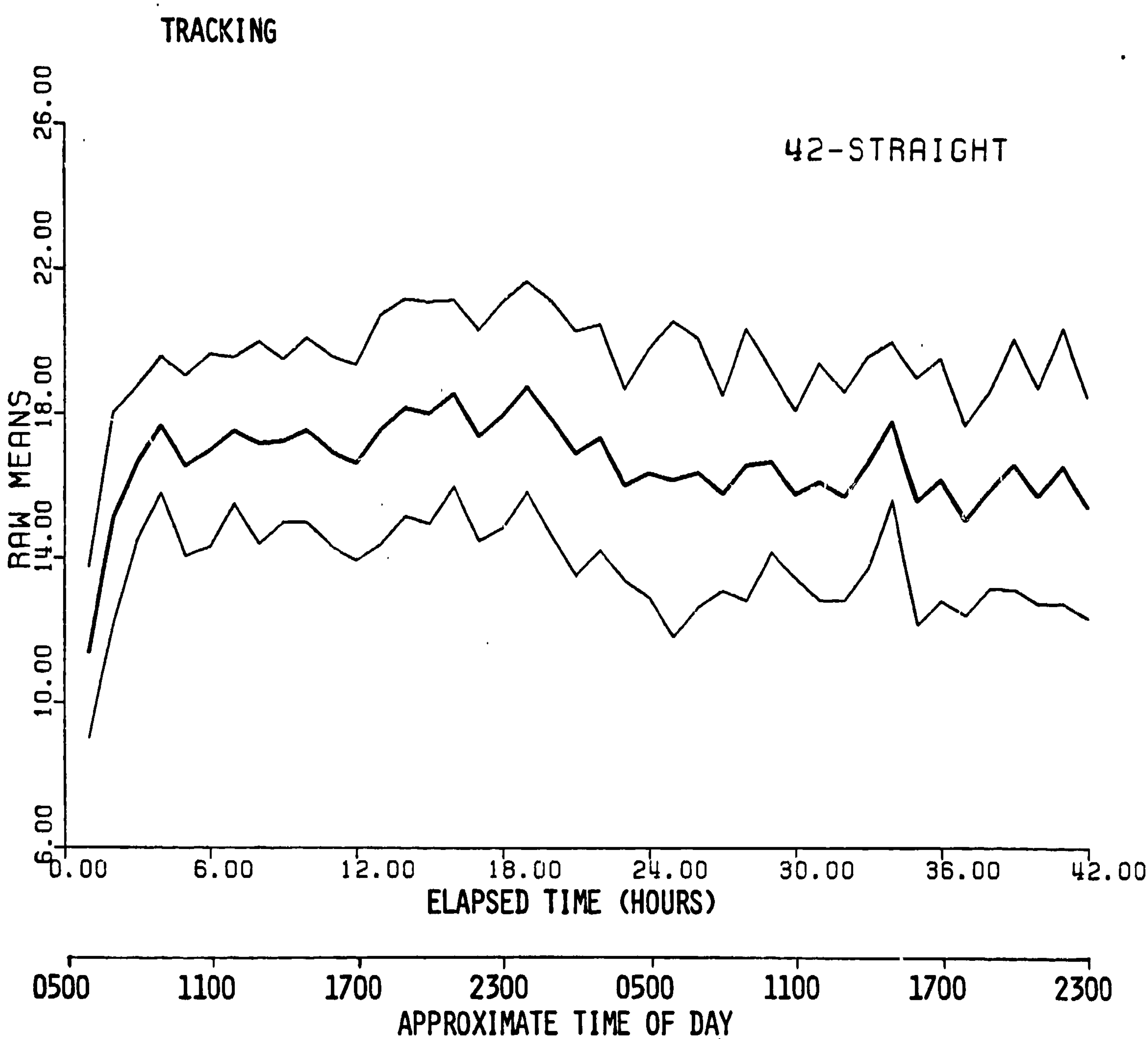



FIG. 3E Hourly means of tracking performance for the 42-straight group. Also plotted are 95% confidence limits.

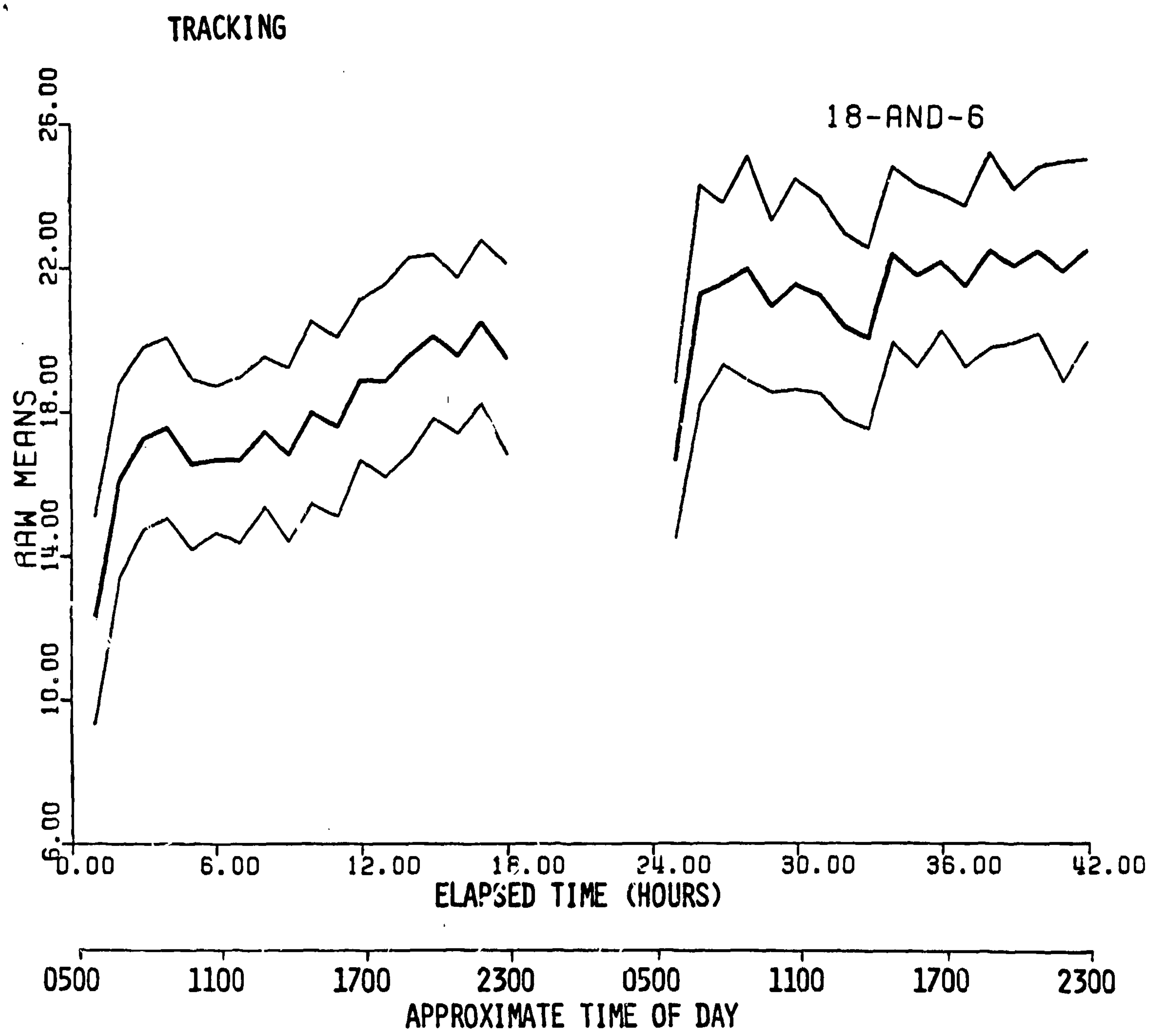



FIG. 3F Hourly means of tracking performance for the 18-and-6 group. Also plotted are 95% confidence limits.

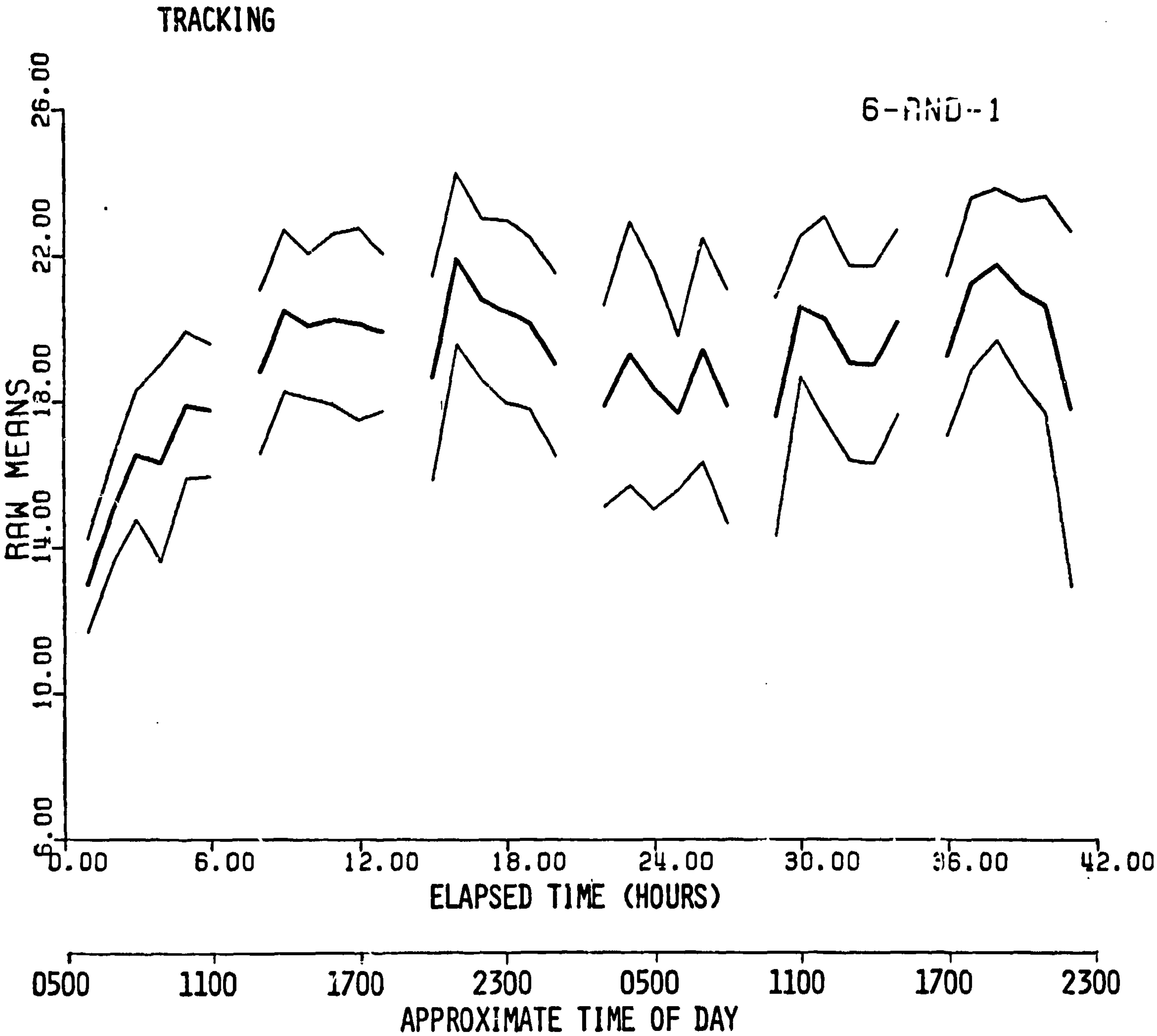



FIG. 3G Hourly means of tracking performance for the 6-and-1 group. Also plotted are 95% confidence limits.

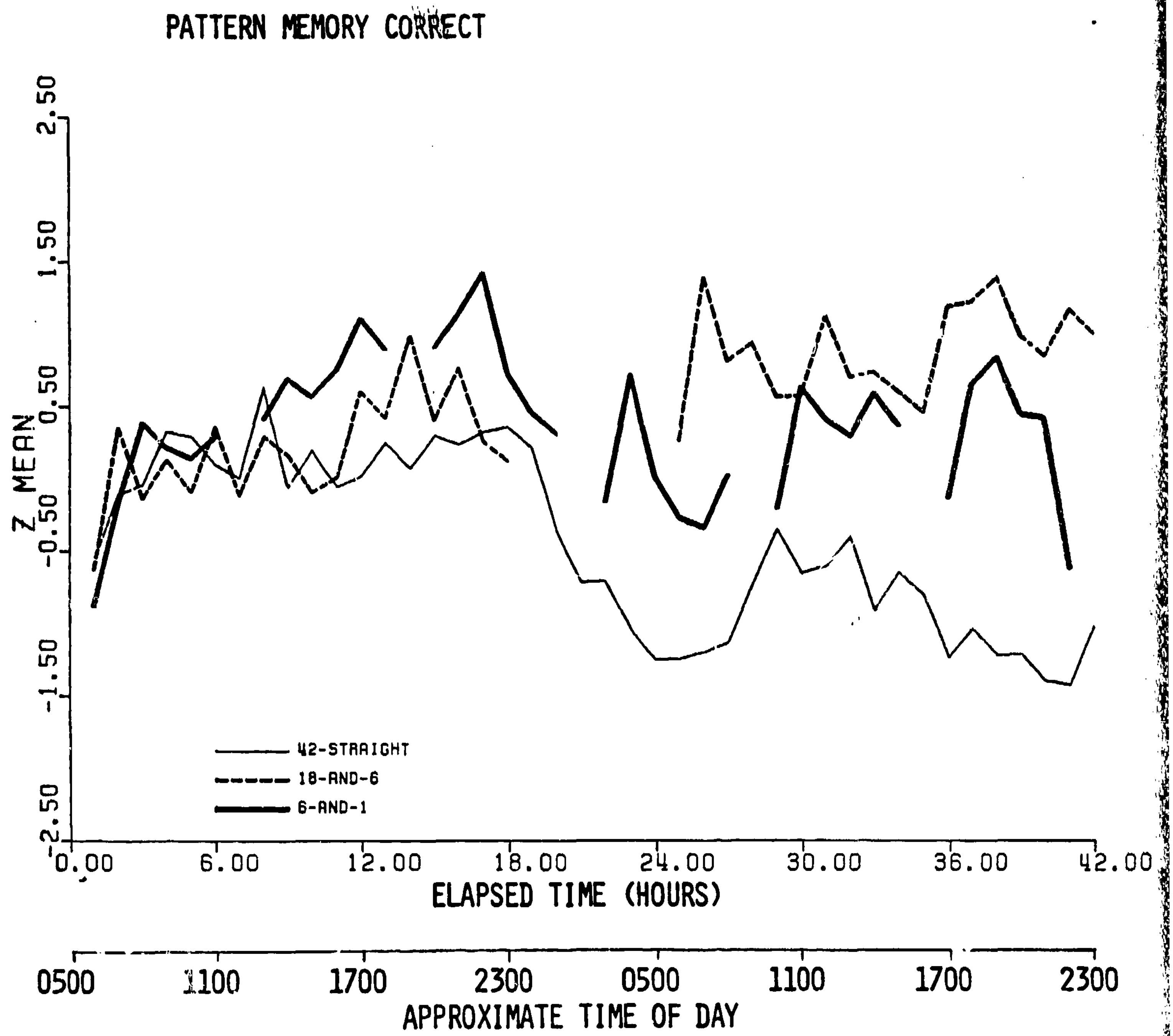



FIG. 4A Hourly means of normalized pattern memory performance for the three experimental groups. Group data are plotted with the mean z-score of the first 6 hours set to the 0 level on the ordinate. Means were derived from z-scores for the entire data of each subject.

PATTERN MEMORY CORRECT

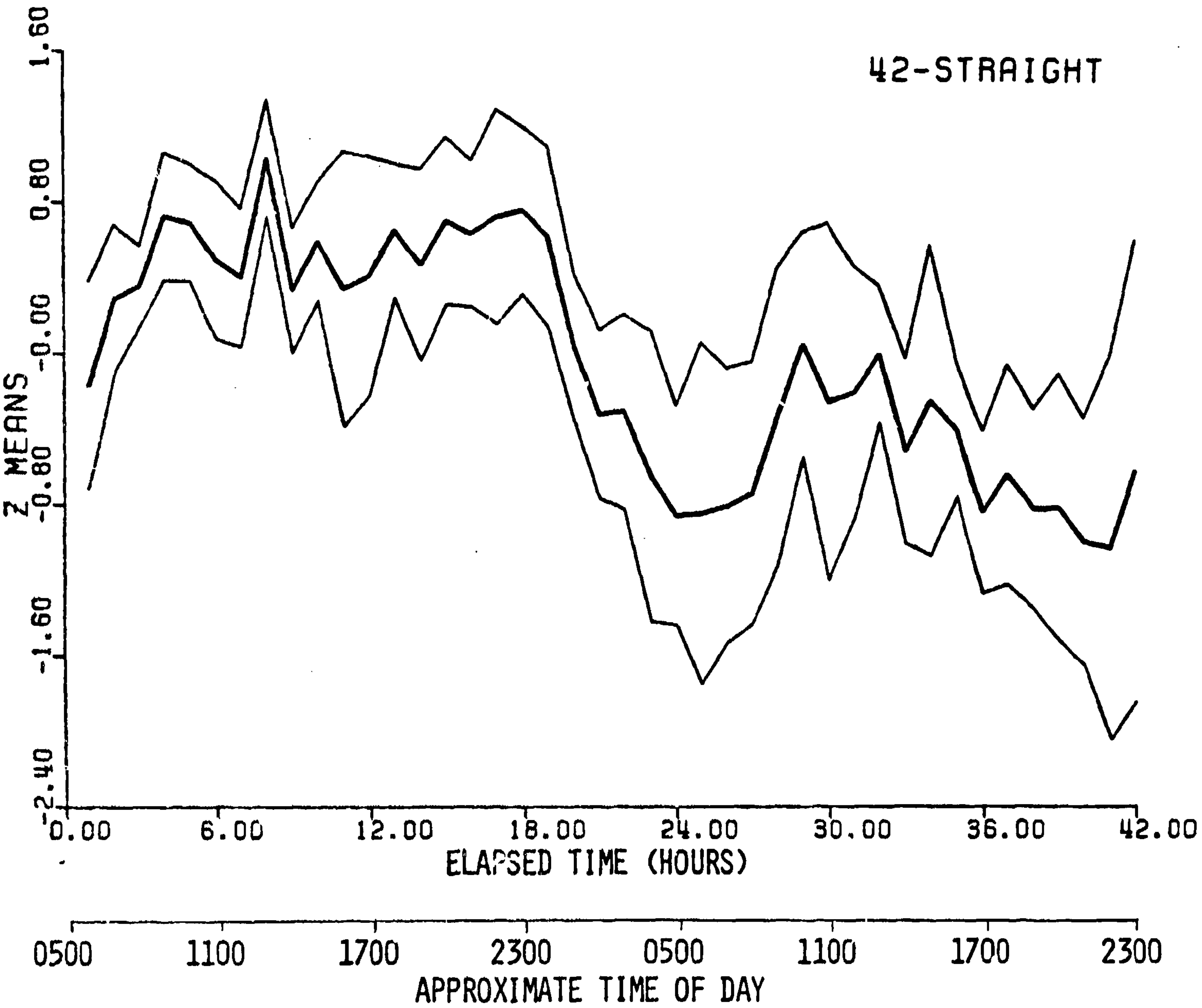



FIG. 4B Hourly means of normalized pattern memory performance for the 42-straight group. Means were derived from z-scores for the entire data of each subject. Also plotted are 95% confidence limits.

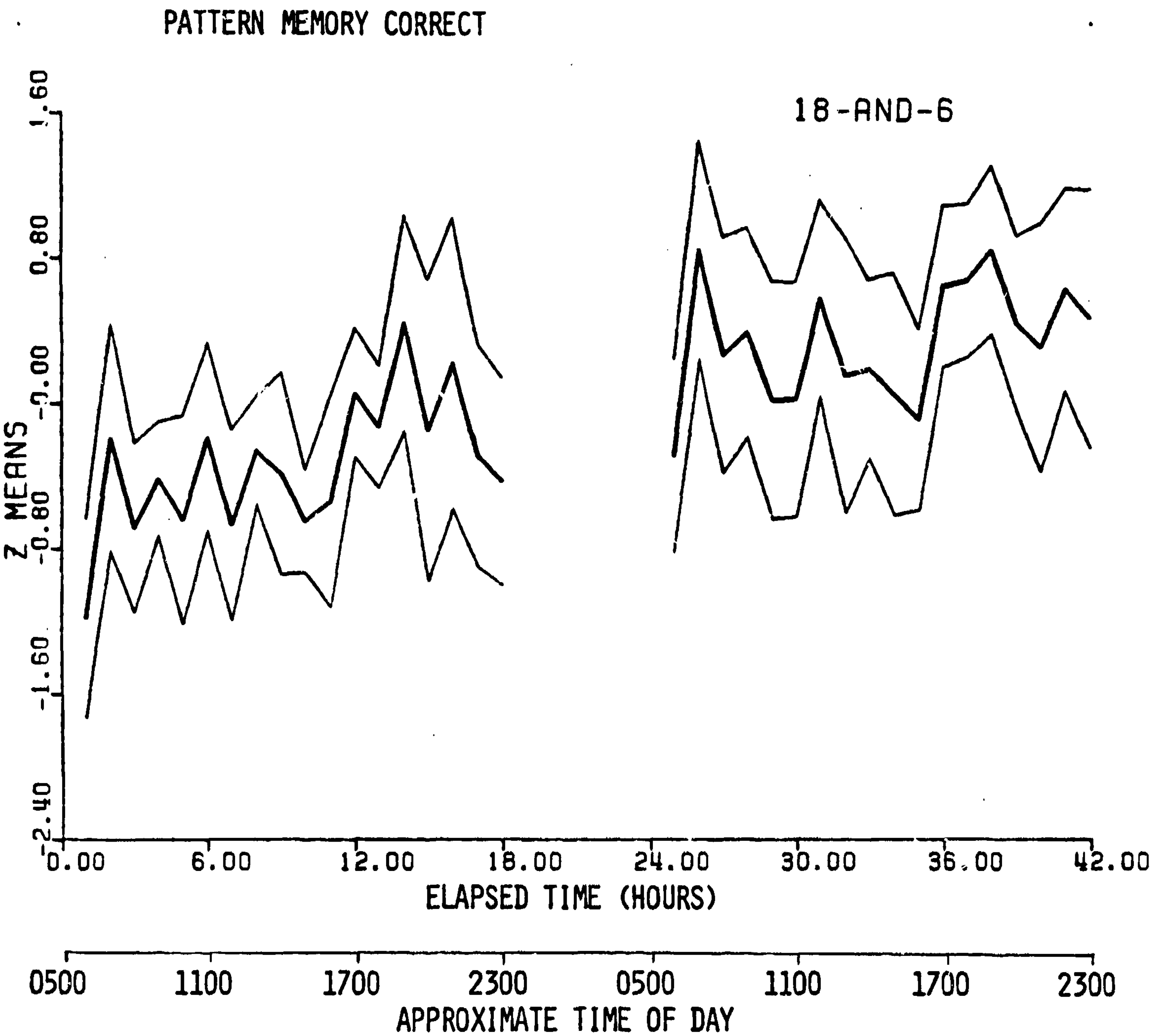



FIG. 4C Hourly means of normalized pattern memory performance for the 18-and-6 group. Means were derived from z-scores for the entire data of each subject. Also plotted are 95% confidence limits.

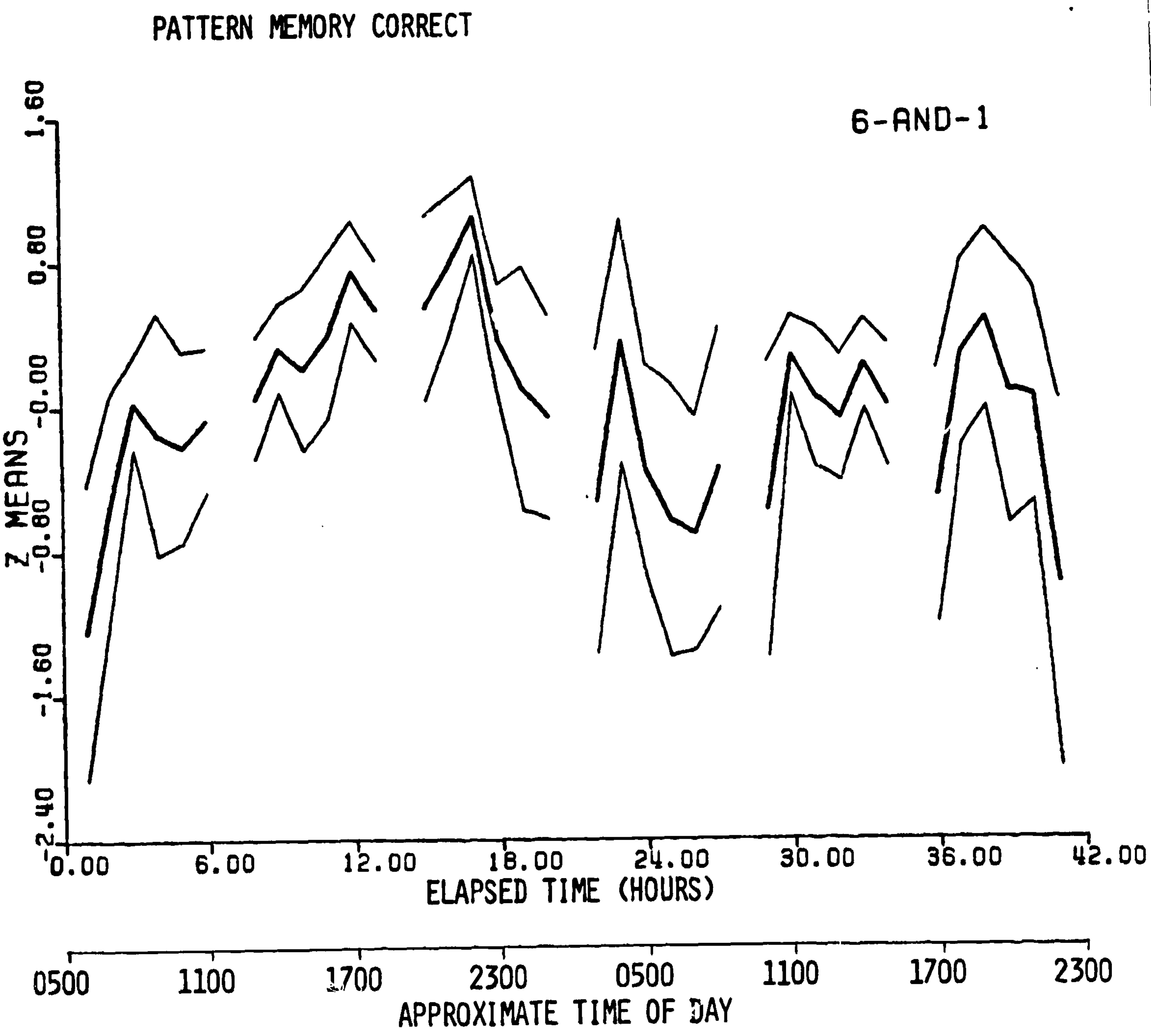



FIG. 4D Hourly means of normalized pattern memory performance for the 6-and-1 group. Means were derived from z-scores for the entire data of each subject. Also plotted are 95% confidence limits.

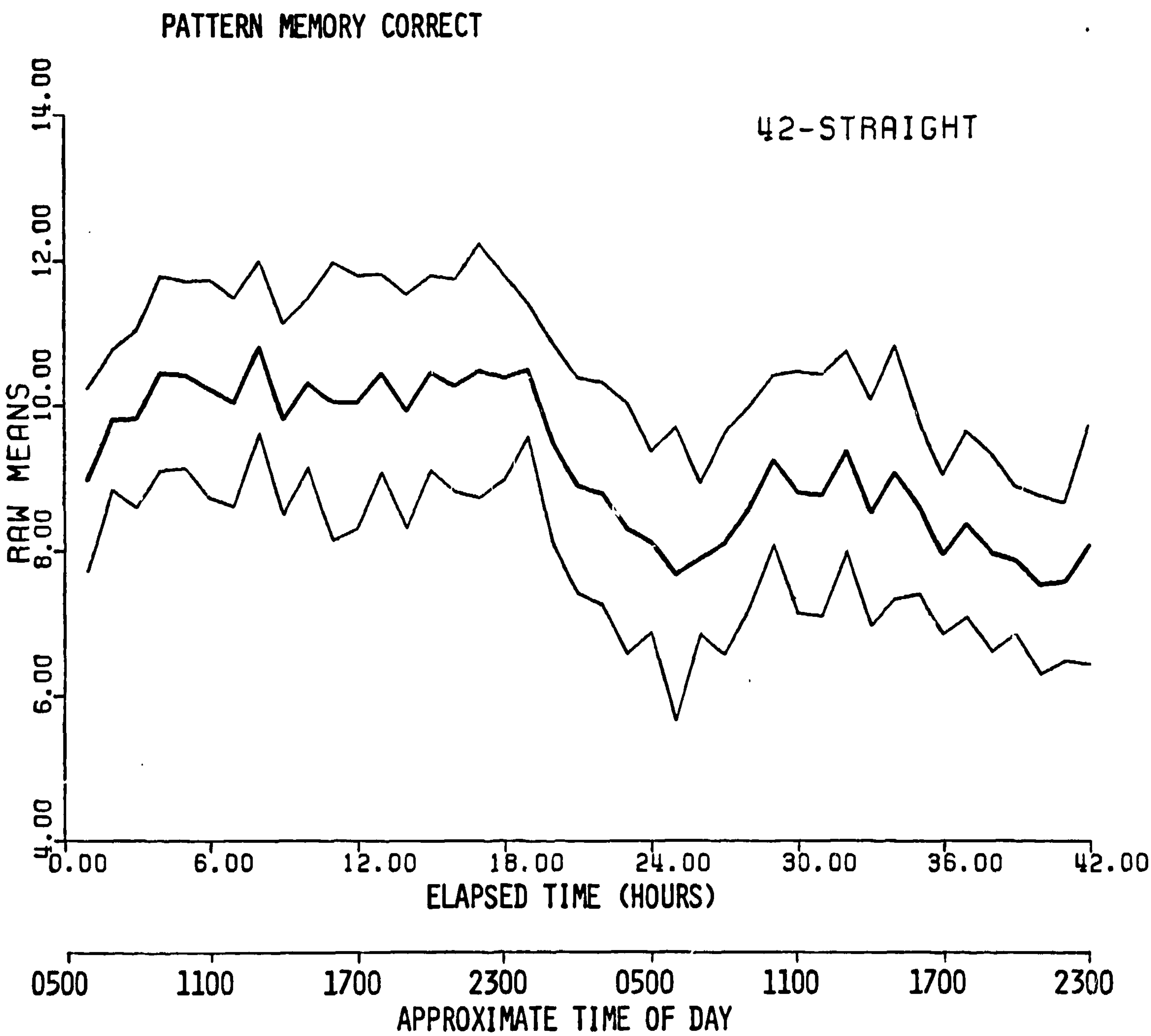



FIG. 4E Hourly means of pattern memory performance for the 42-straight group. Also plotted are 95% confidence limits.

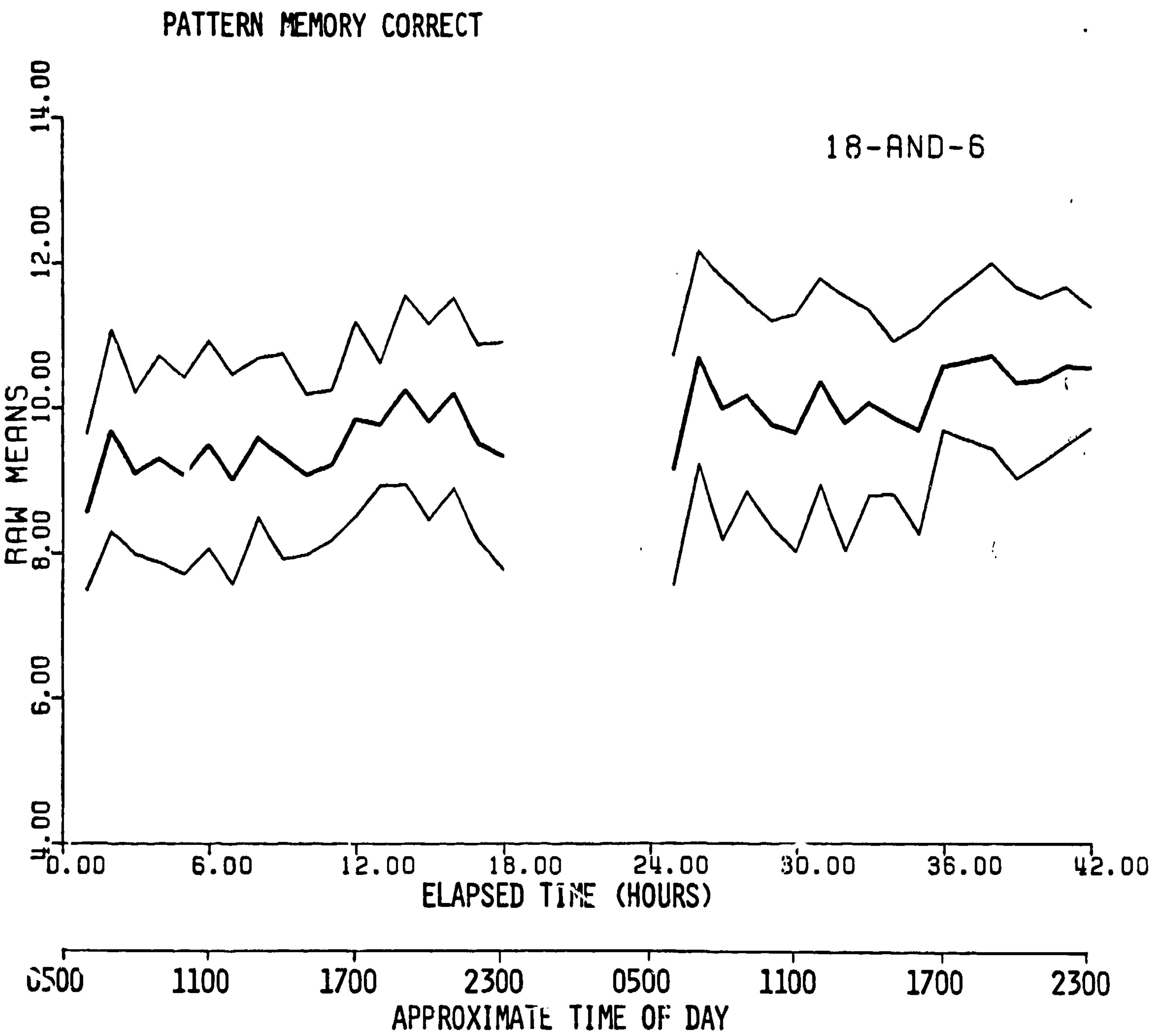



FIG. 4F Hourly means of pattern memory performance for the 18-and-6 group. Also plotted are 95% confidence limits.

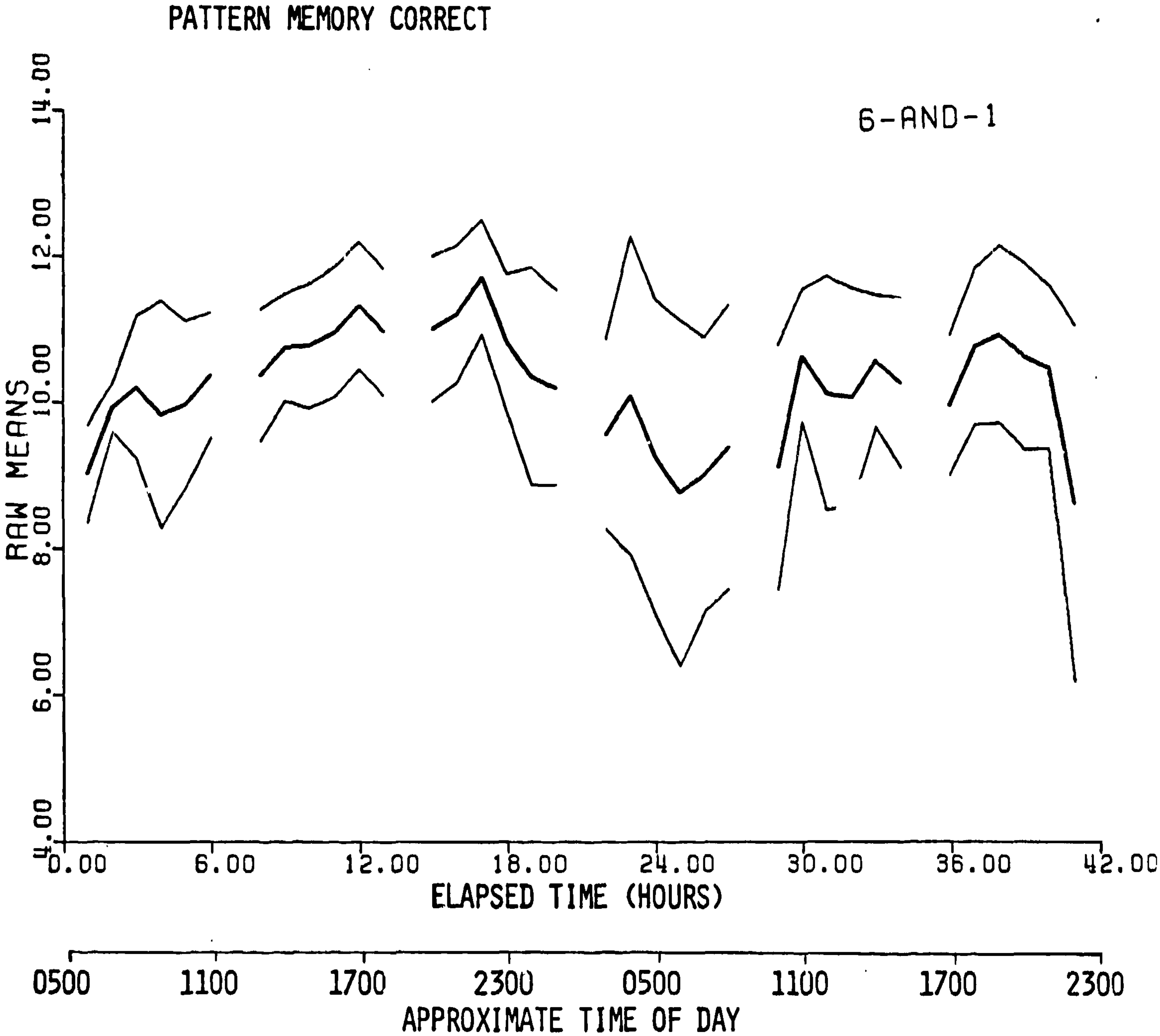



FIG. 4G Hourly means of pattern memory performance for the 6-and-1 group. Also plotted are 95% confidence limits.

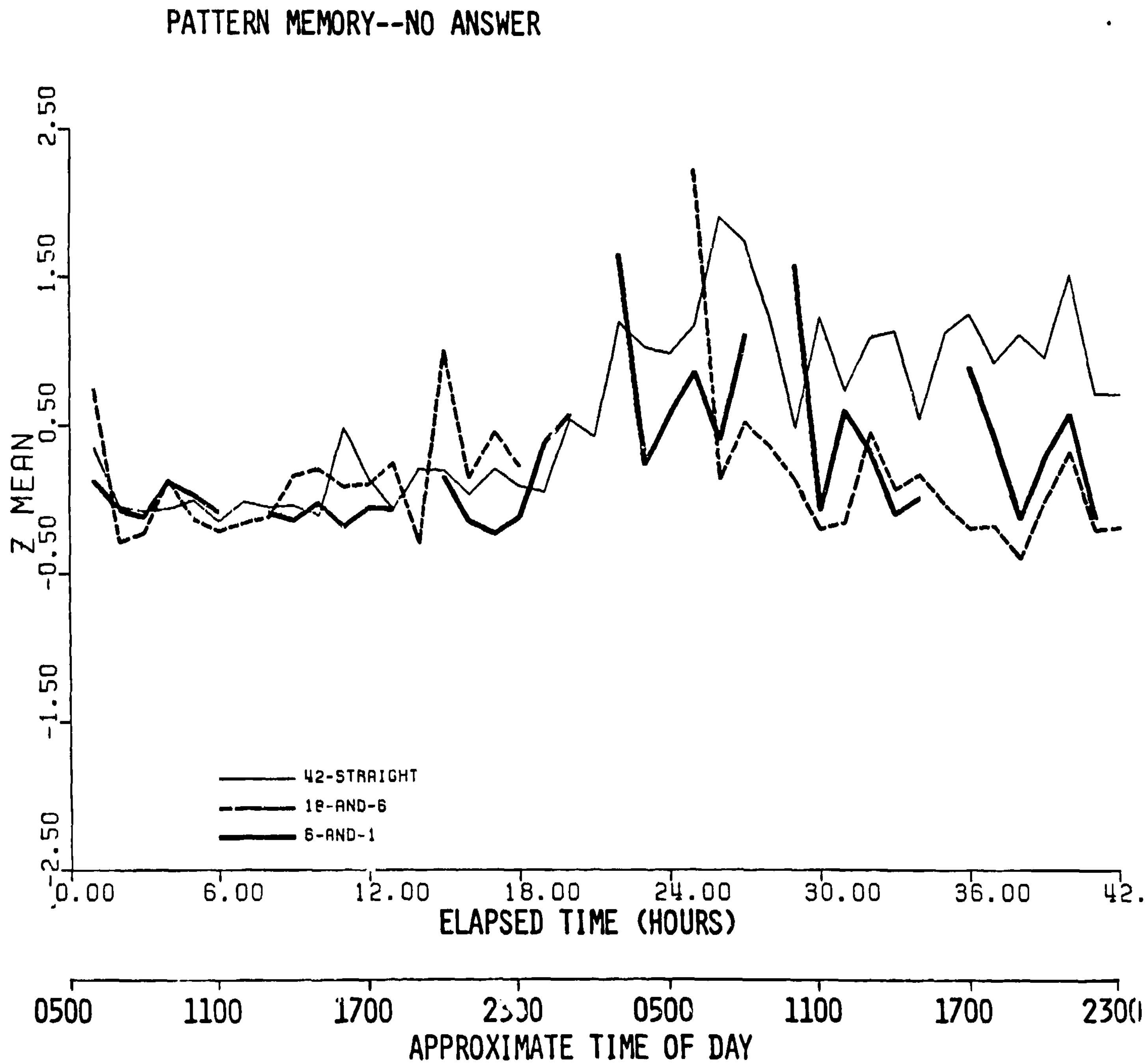



FIG. 5A Hourly means of normalized numbers of failures to respond (no answer) during the pattern memory task for the three experimental groups. Group data are plotted with the mean z-score fo the first 6 hours set to the 0 level on the ordinate. Means were derived from z-scores for the entire data of each subject.

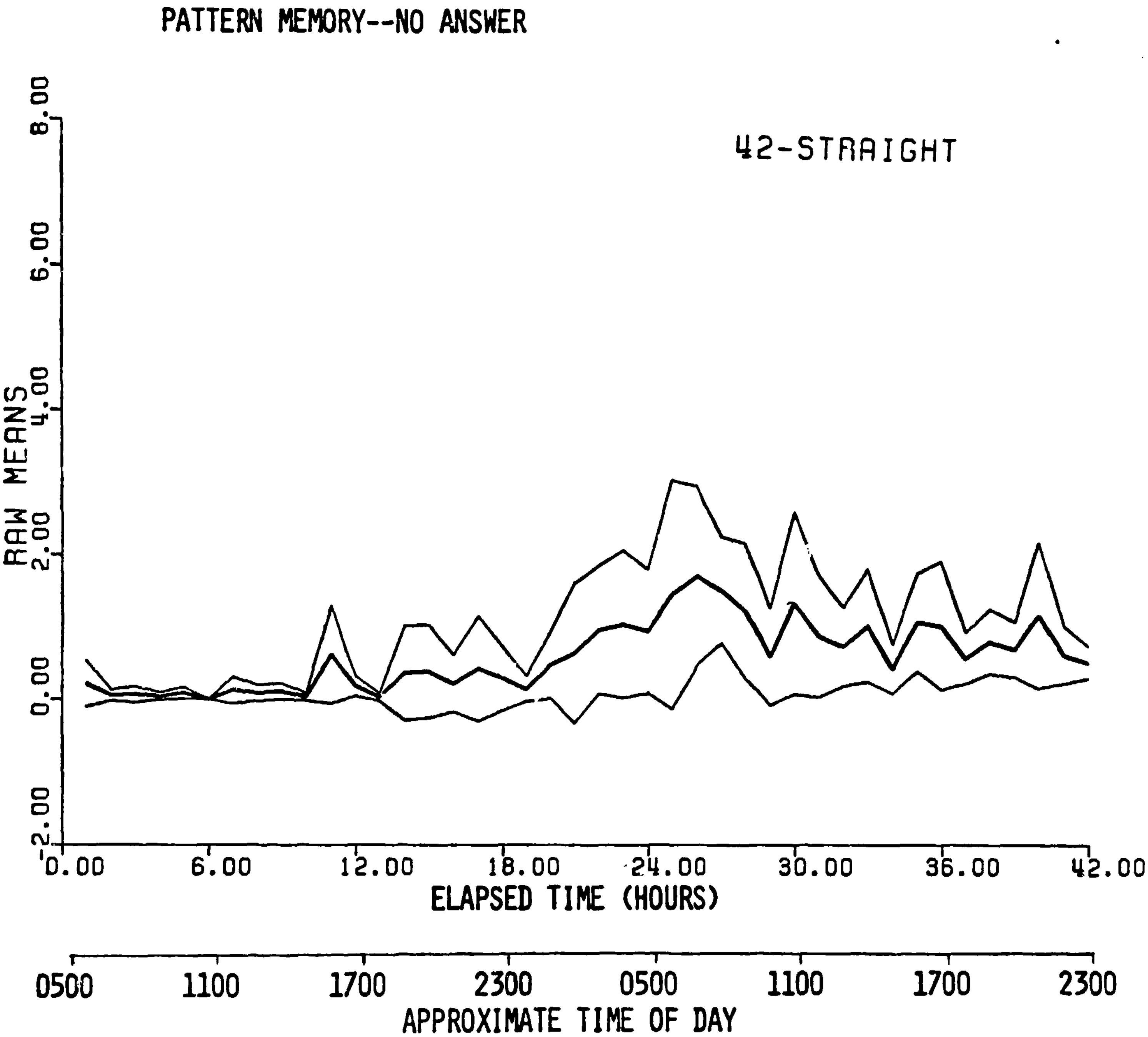



FIG. 5B Hourly means of the number of failures to respond (no answer) during the pattern memory task for the 42-straight group. Also plotted are 95% confidence limits.

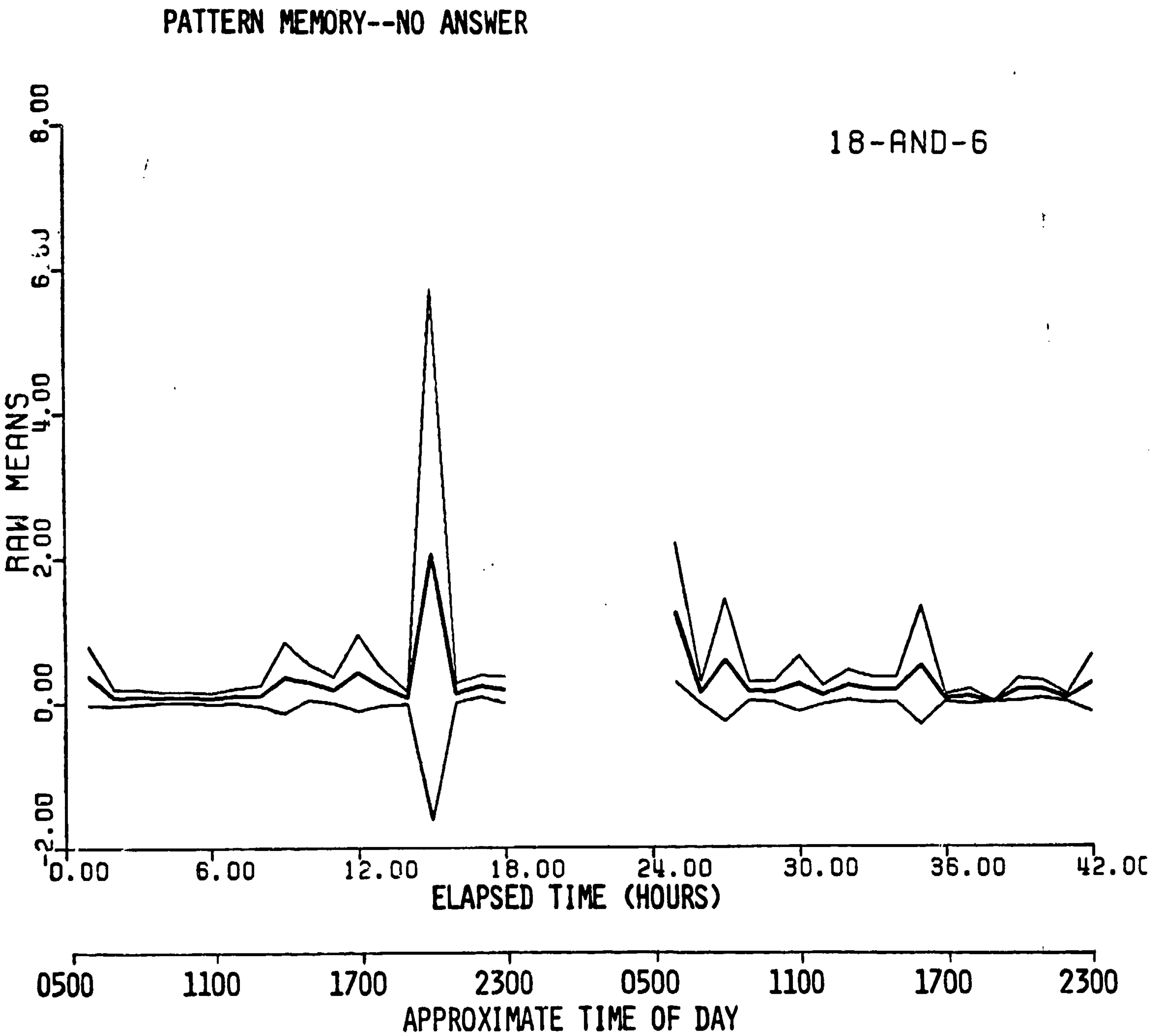



FIG. 5C Hourly means of the number of failures to respond (no answer) during the pattern memory task for the 18-and-6 group. Also plotted are 95% confidence limits.

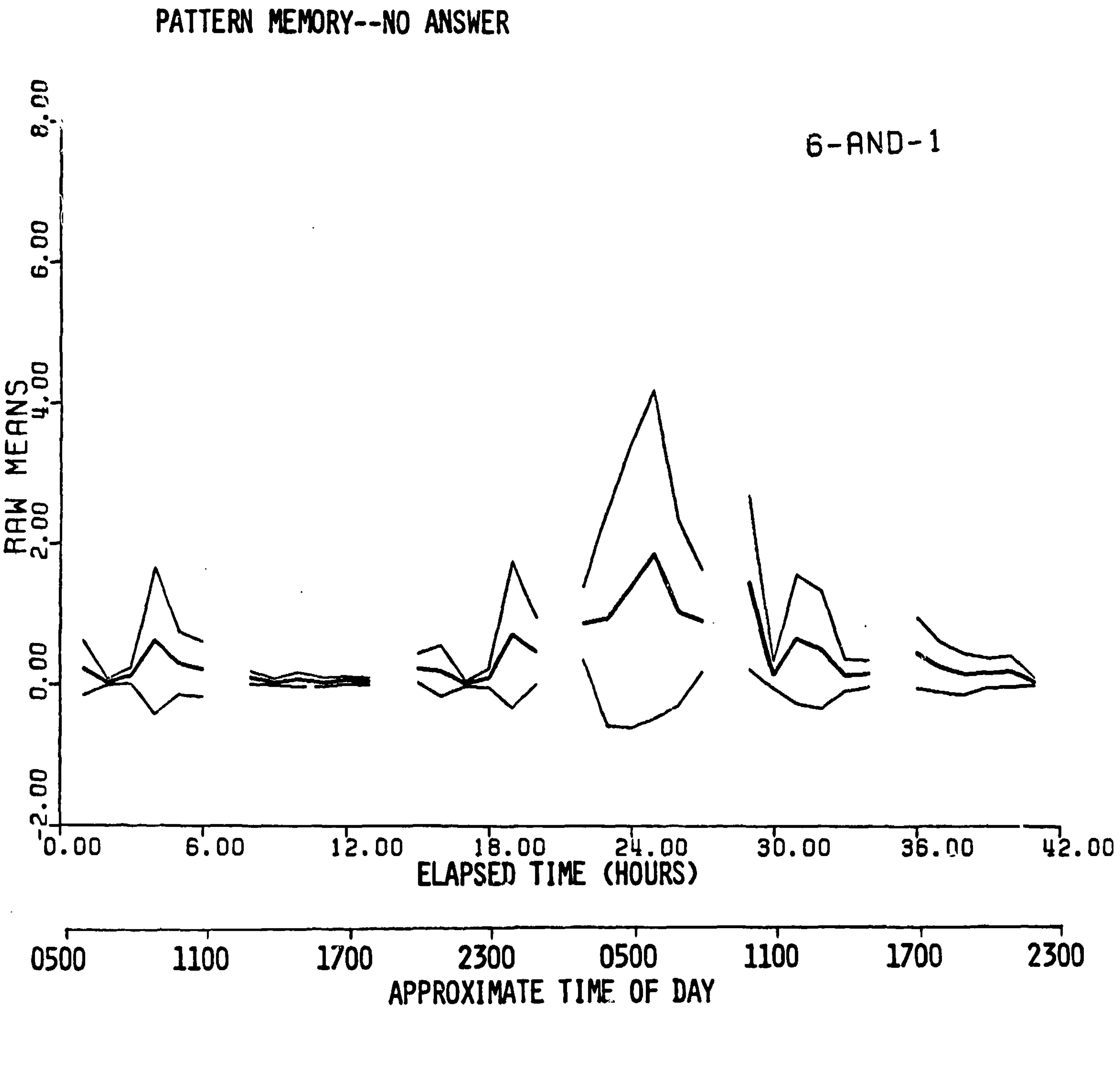



FIG. 5D Hourly means of the number of failures to respond (no answer) during the pattern memory task for the 6-and-1 group. Also plotted are 95% confidence limits.

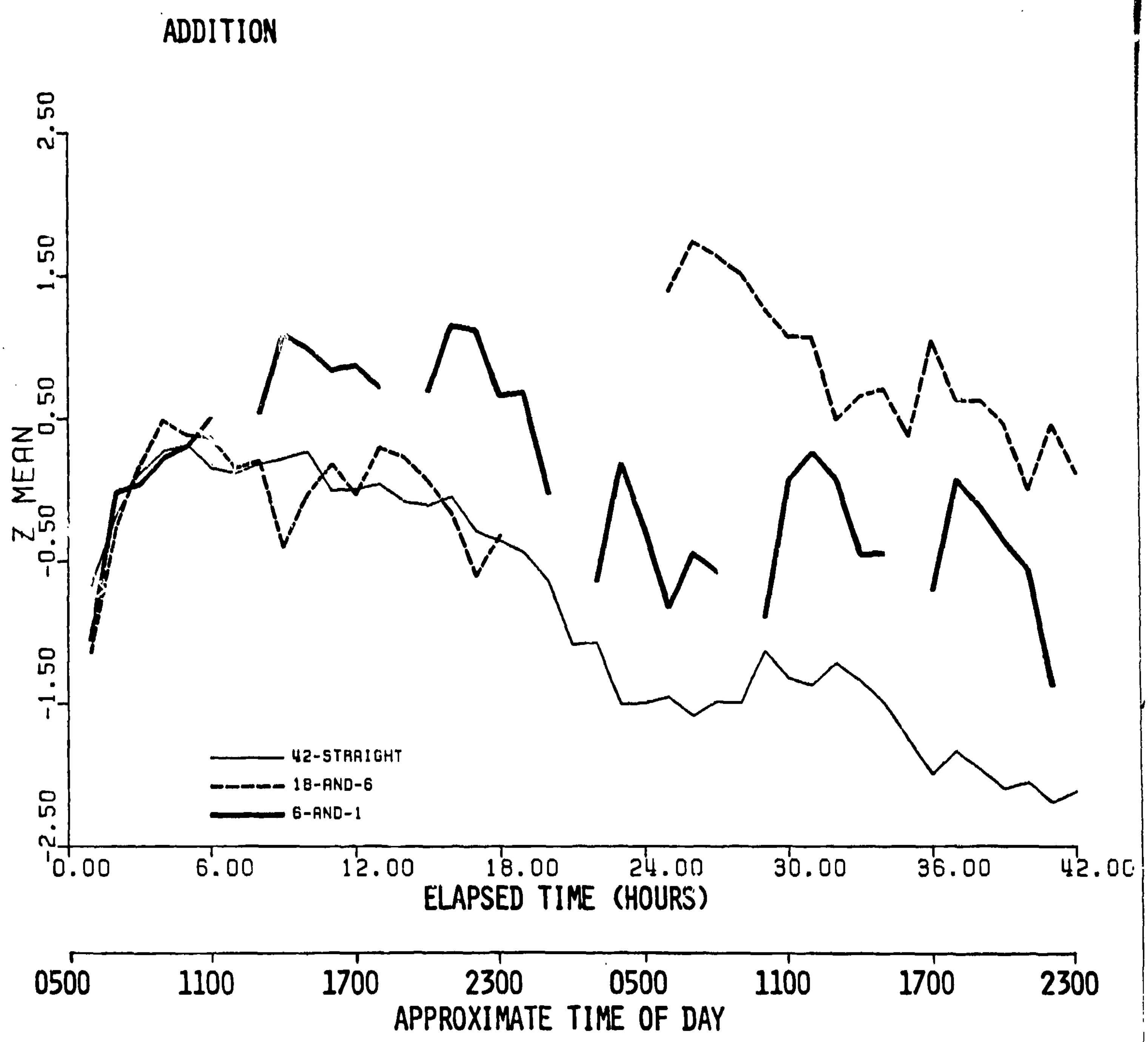



FIG. 6A Hourly means of normalized addition performance for the three experimental groups. Group data are plotted with the mean z-score of the first 6 hours set to the 0 level on the ordinate. Means were derived from z-scores for the entire data of each subject.

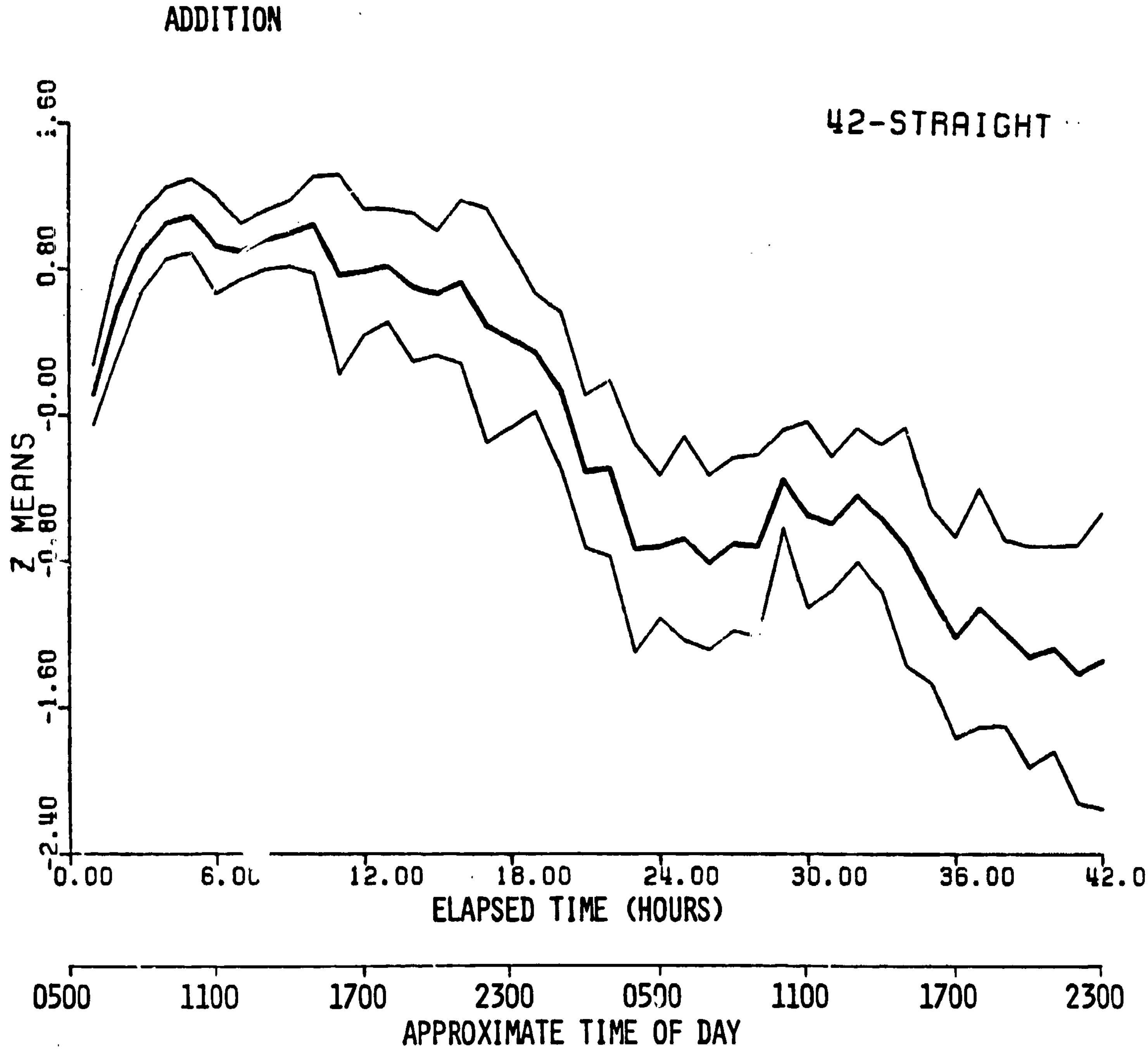



FIG. 6B Hourly means of normalized addition performance for the 42-straight group. Means were derived from z-scores for the entire data of each subject. Also plotted are 95% confidence limits.

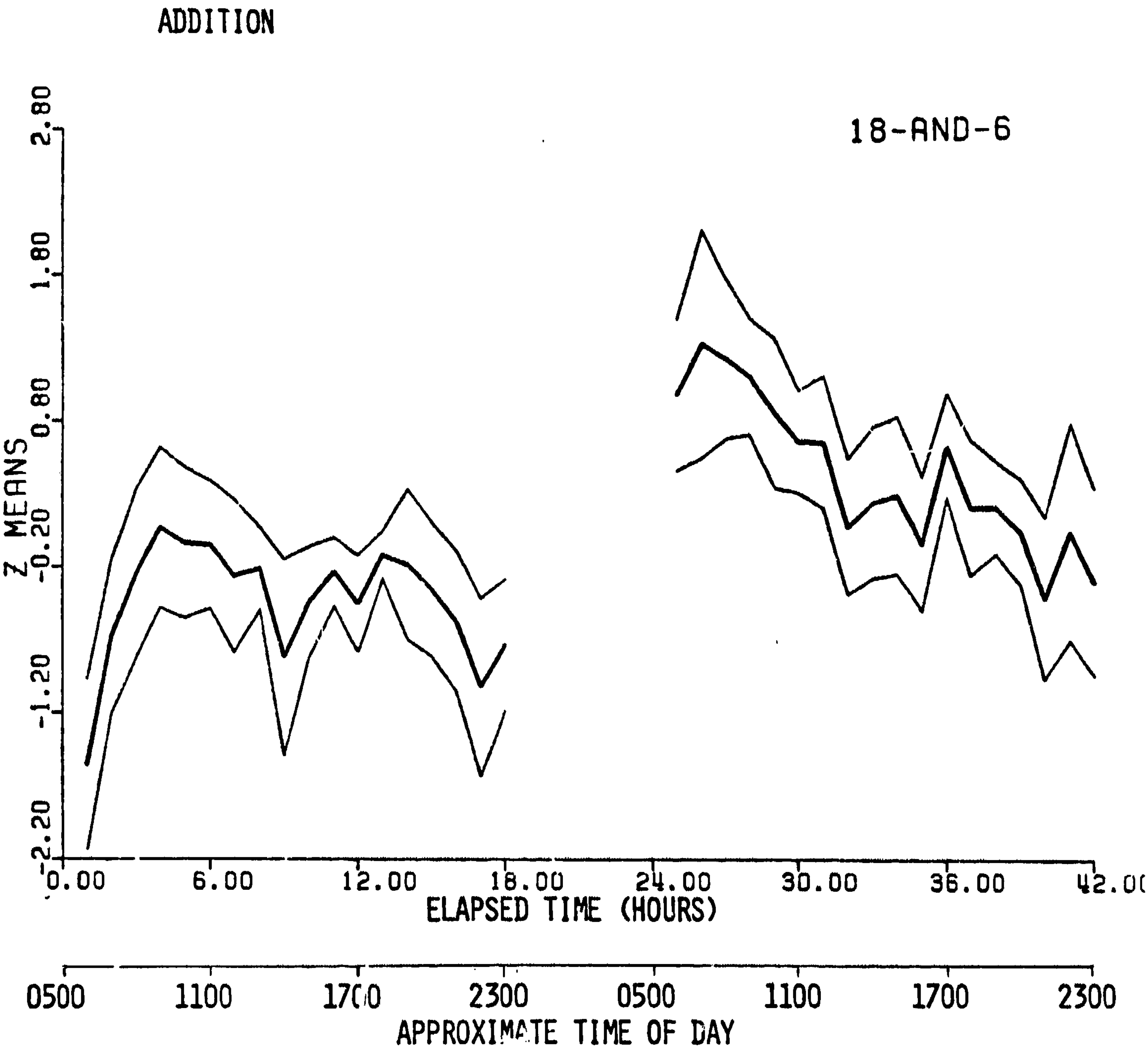



FIG. 6C Hourly means of normalized addition performance for the 18-and-6 group. Means were derived from z-scores for the entire data of each subject. Also plotted are 95% confidence limits.

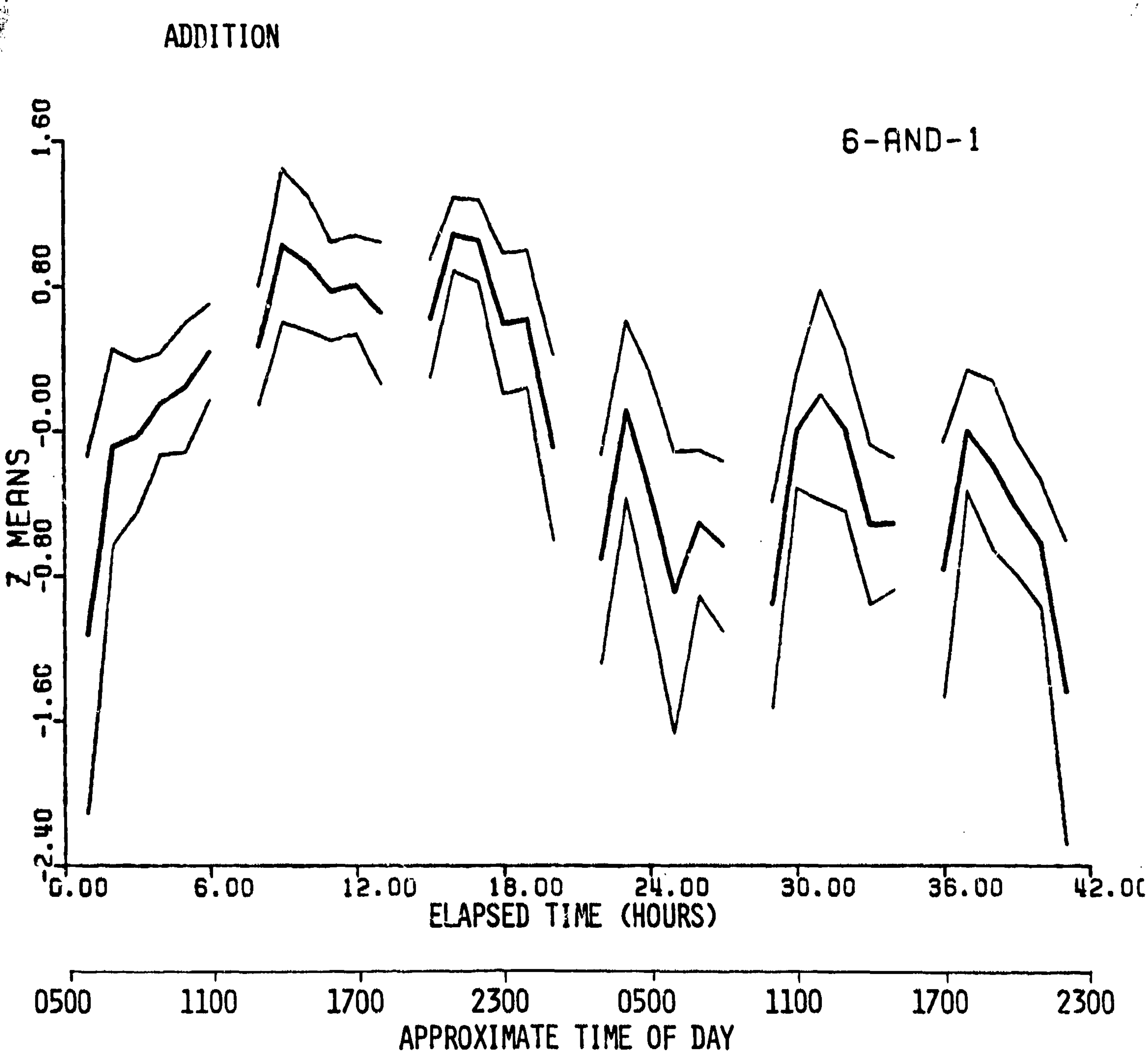



FIG. 6D Hourly means of normalized addition performance for the 6-and-1 group. Means were derived from z-scores for the entire data of each subject. Also plotted are 95% confidence limits.

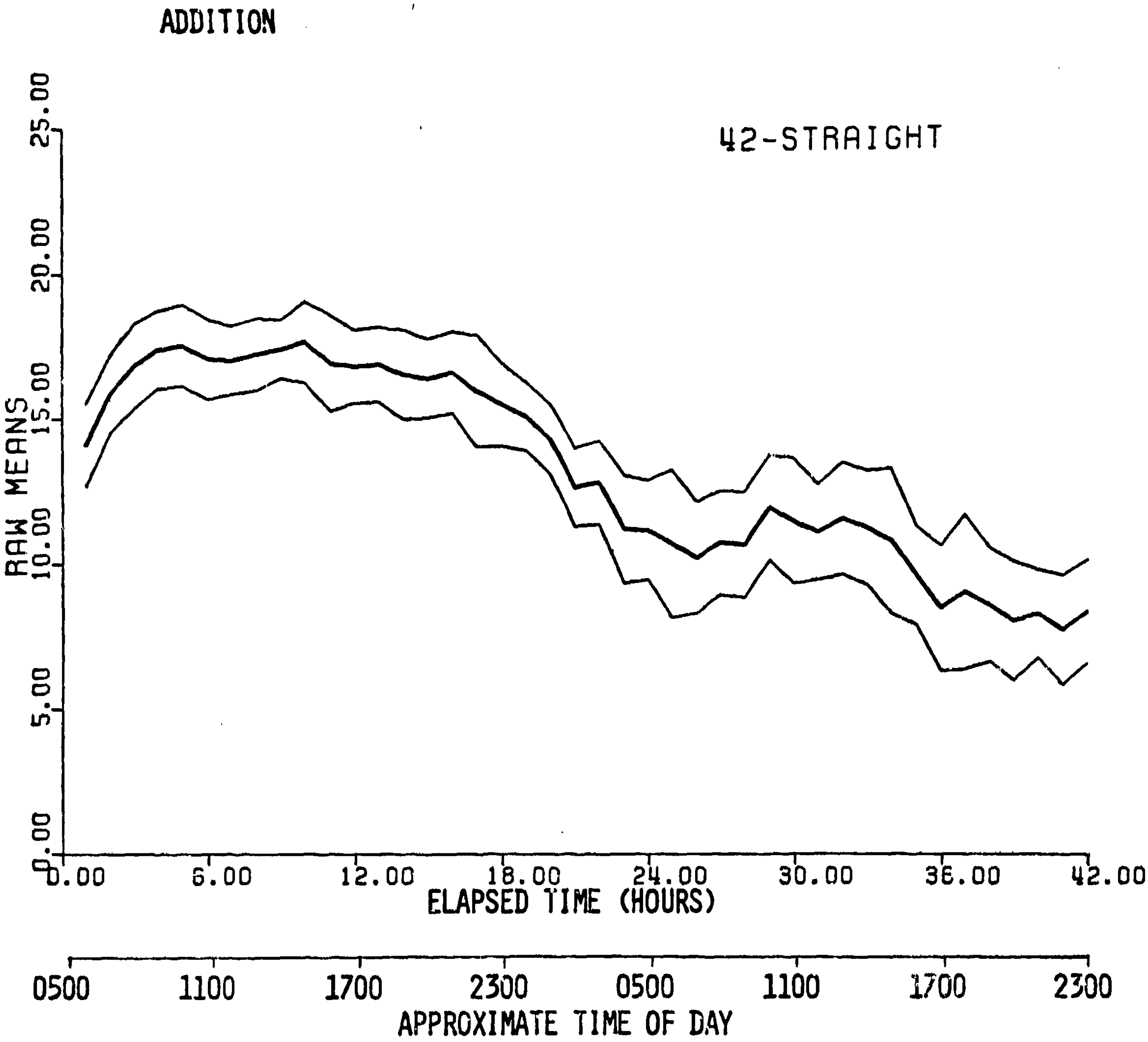



FIG. 6E Hourly means of addition performance for the 42-straight group. Also plotted are 95% confidence limits.

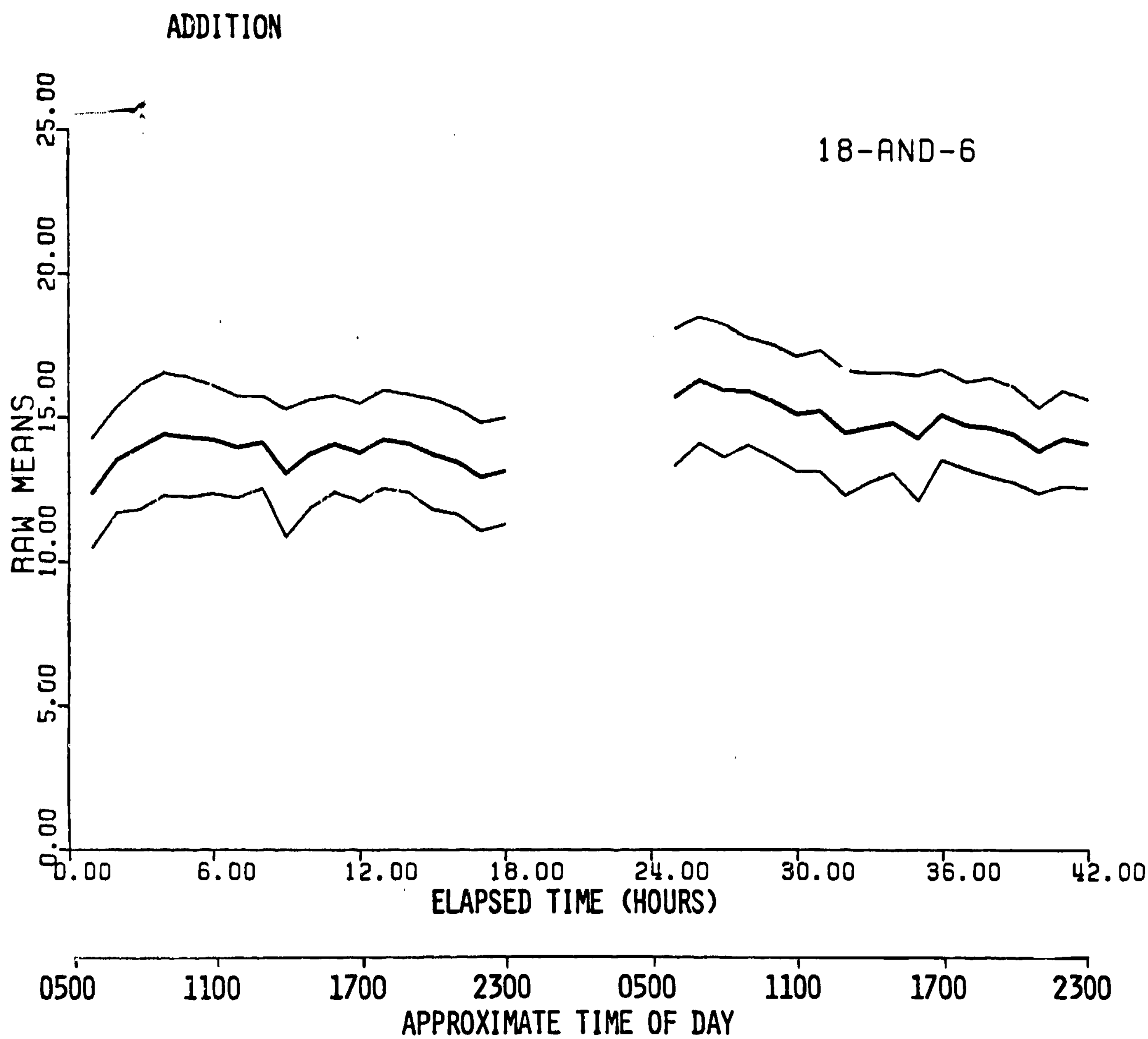



FIG. 6F Hourly means of addition performance for the 18-and-6 group. Also plotted are 95% confidence limits.

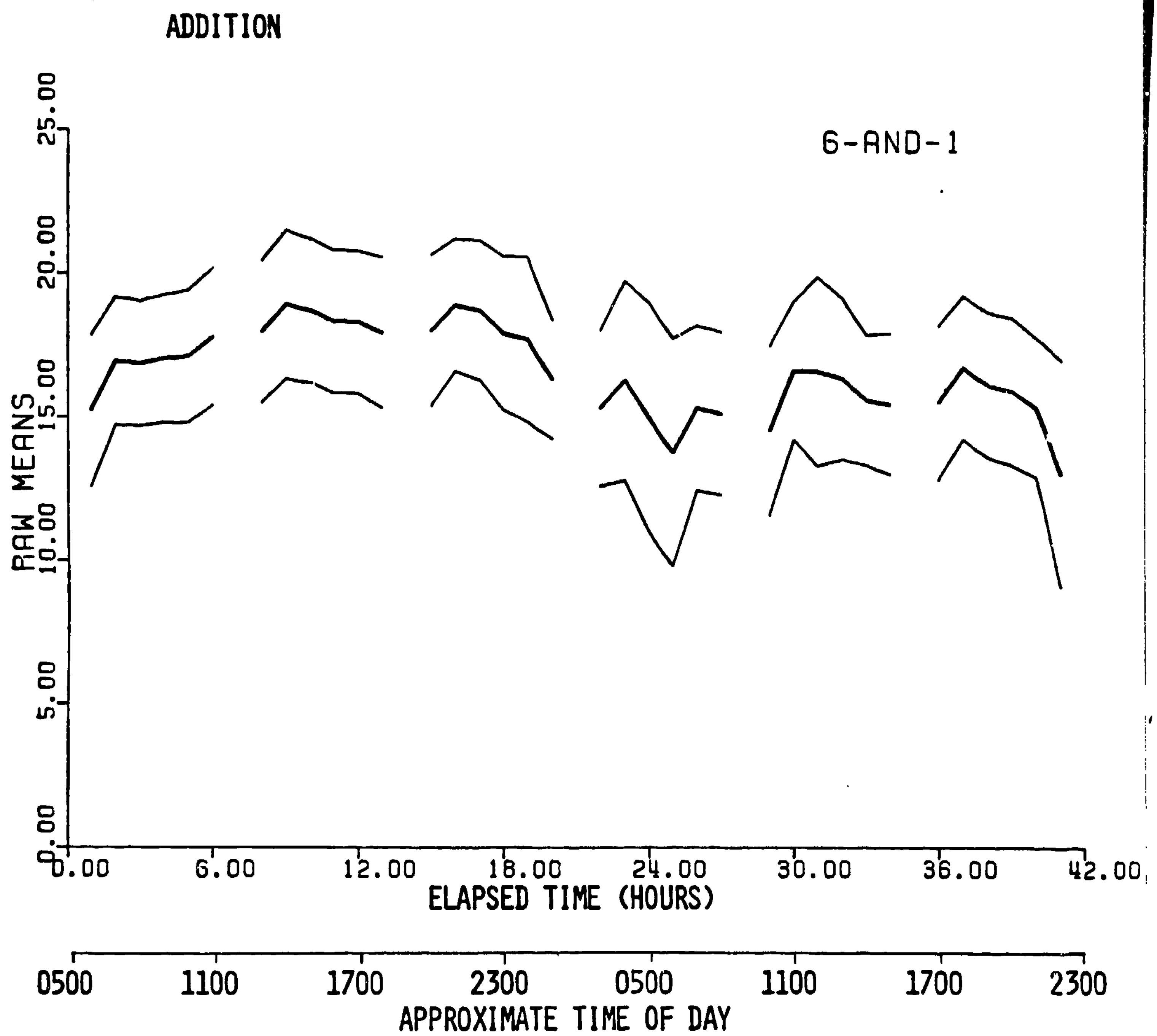



FIG. 6G Hourly means of addition performance for the 6-and-1 group. Also plotted are 95% confidence limits.

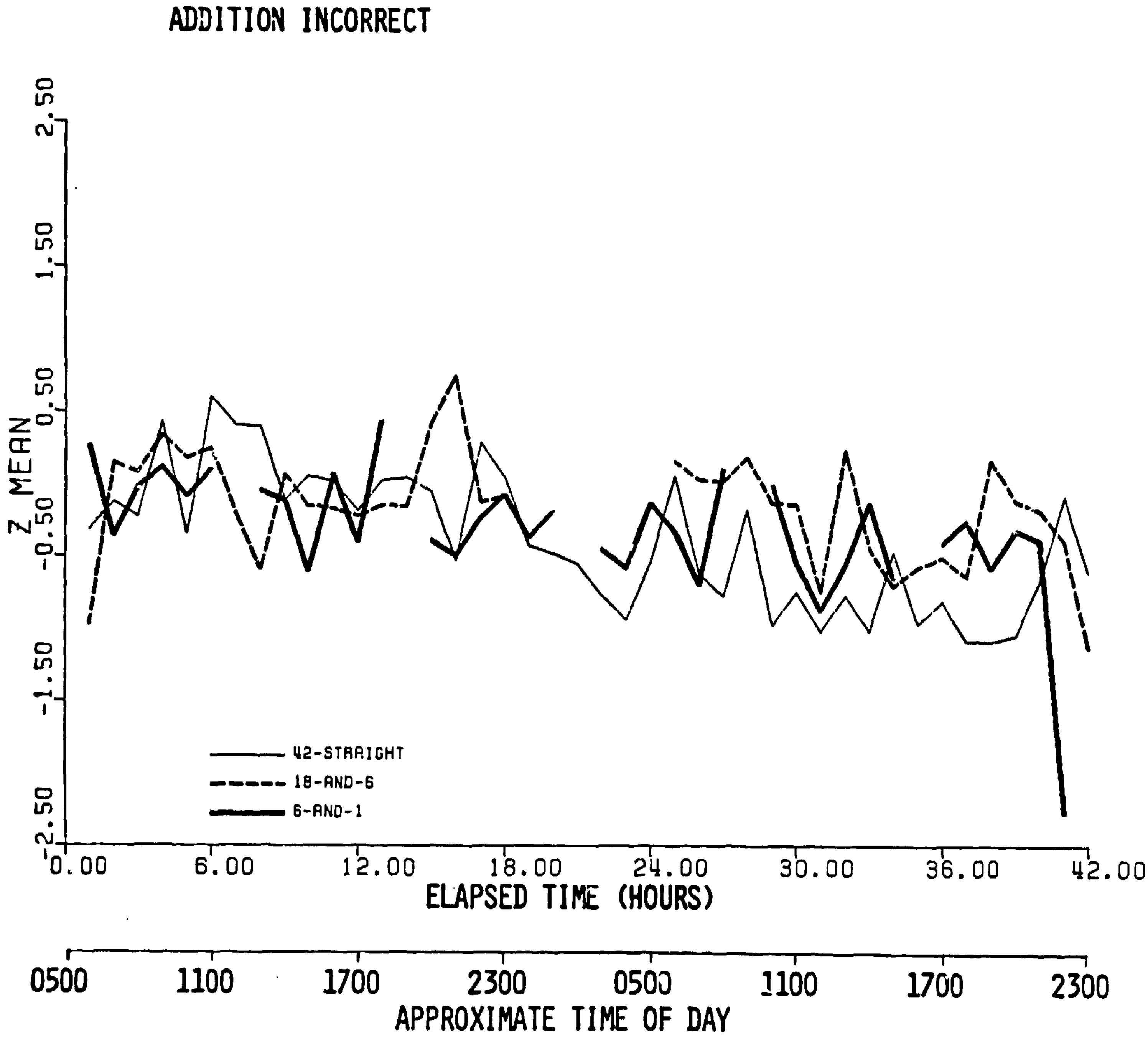



FIG 7A Hourly means of normalized numbers of incorrect additions for the three experimental groups. Group data are plotted with the mean z-score of the first 6 hours set to the 0 level on the ordinate. Means were derived from z-scores for the entire data of each subject.

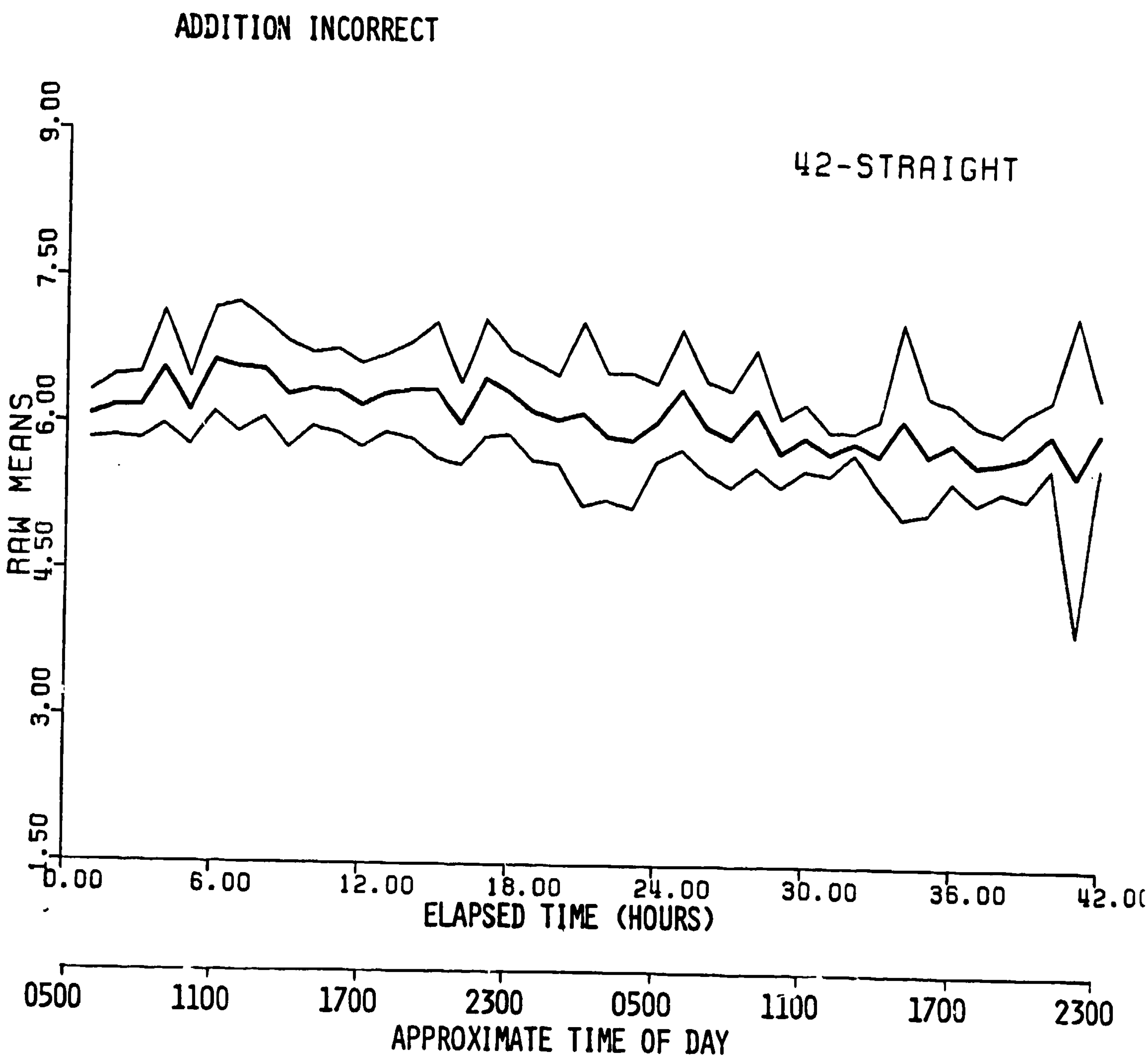



FIG. 7B Hourly means of incorrect additions for the 42-straight group. Also plotted are 95% confidence limits.

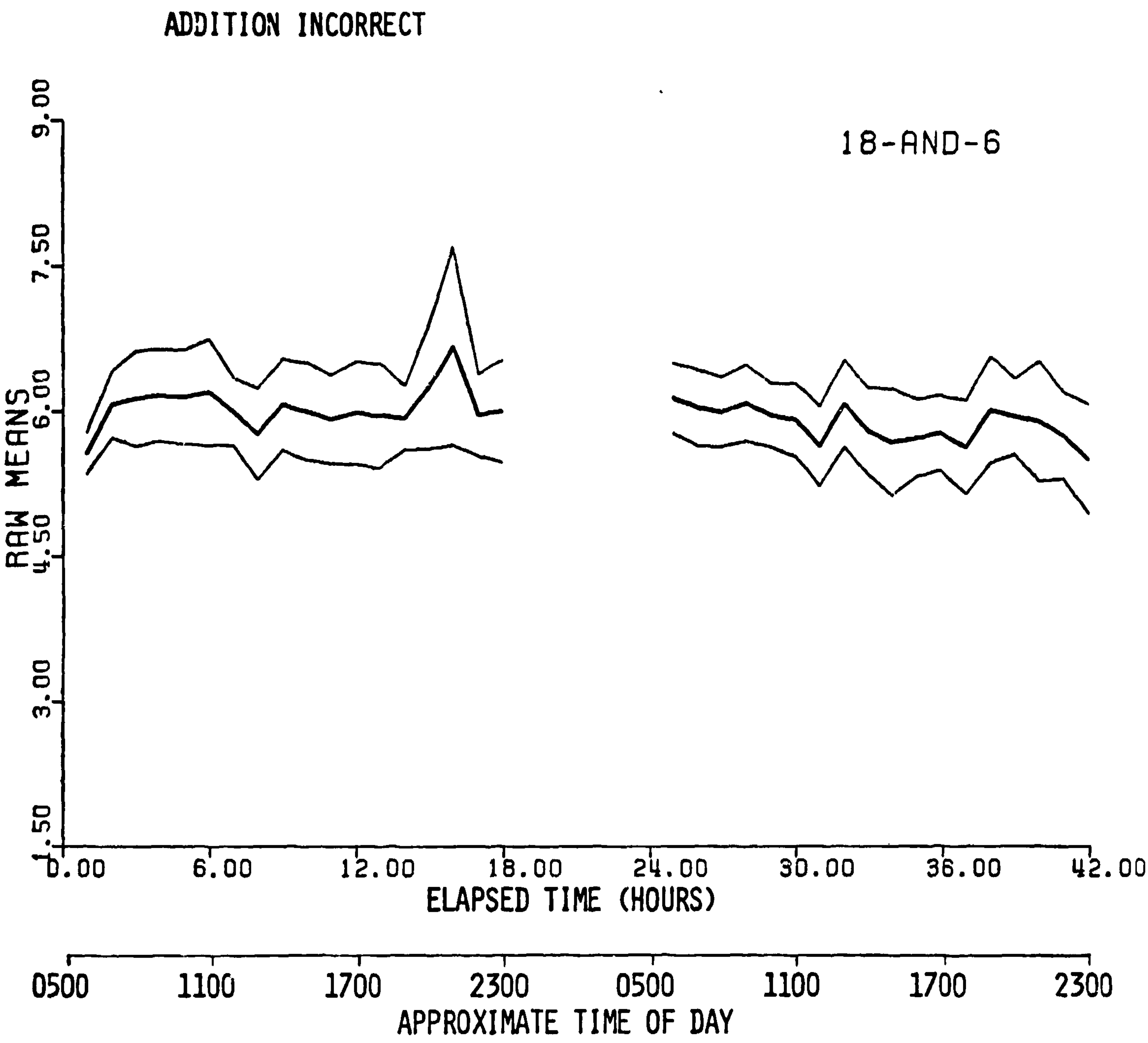



FIG. 7C Hourly means of incorrect additions for the 18-and-6 group. Also plotted are 95% confidence limits.

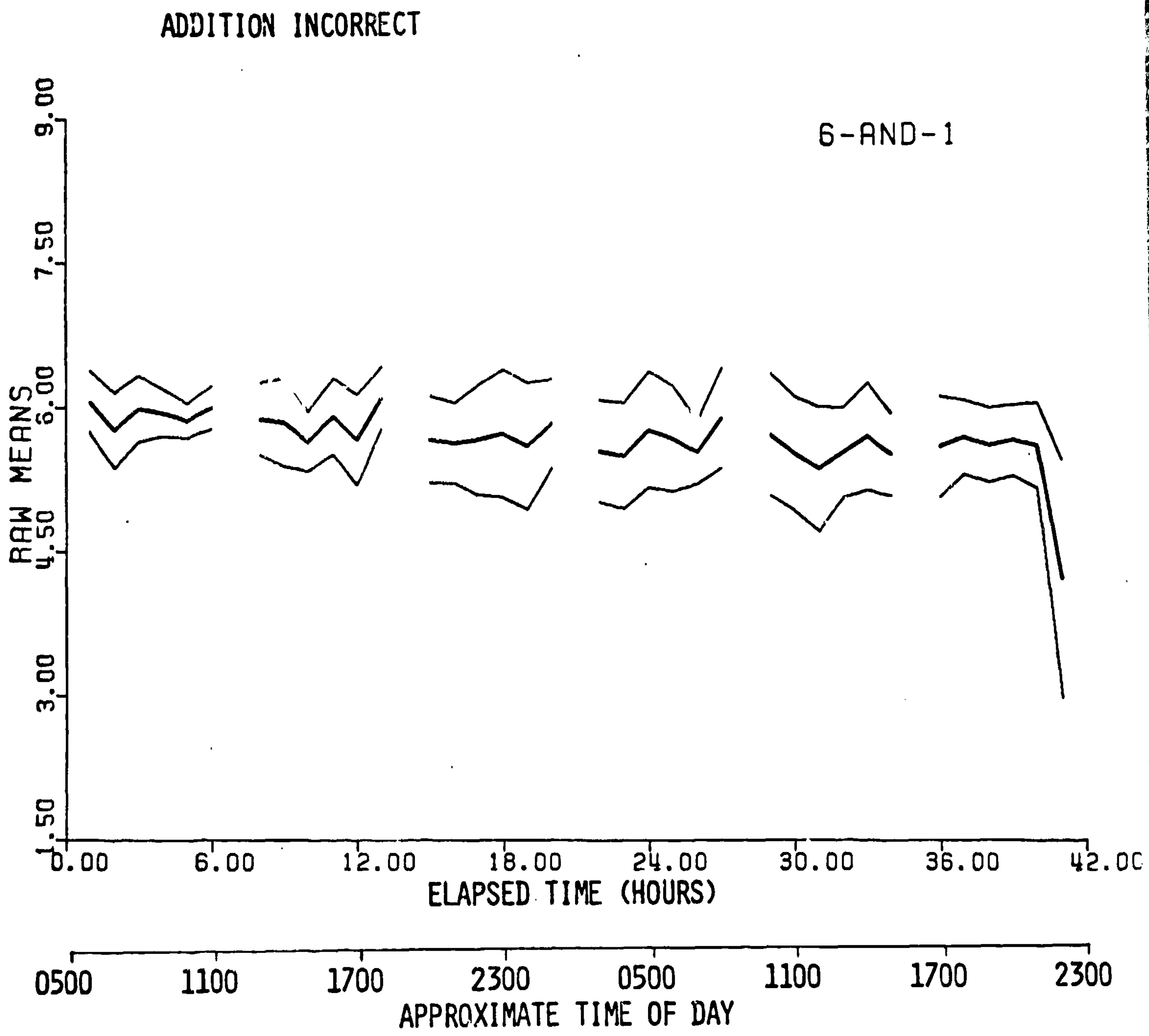



FIG. 7D Hourly means of incorrect additions for the 6-and-1 group. Also plotted are 95% confidence limits.

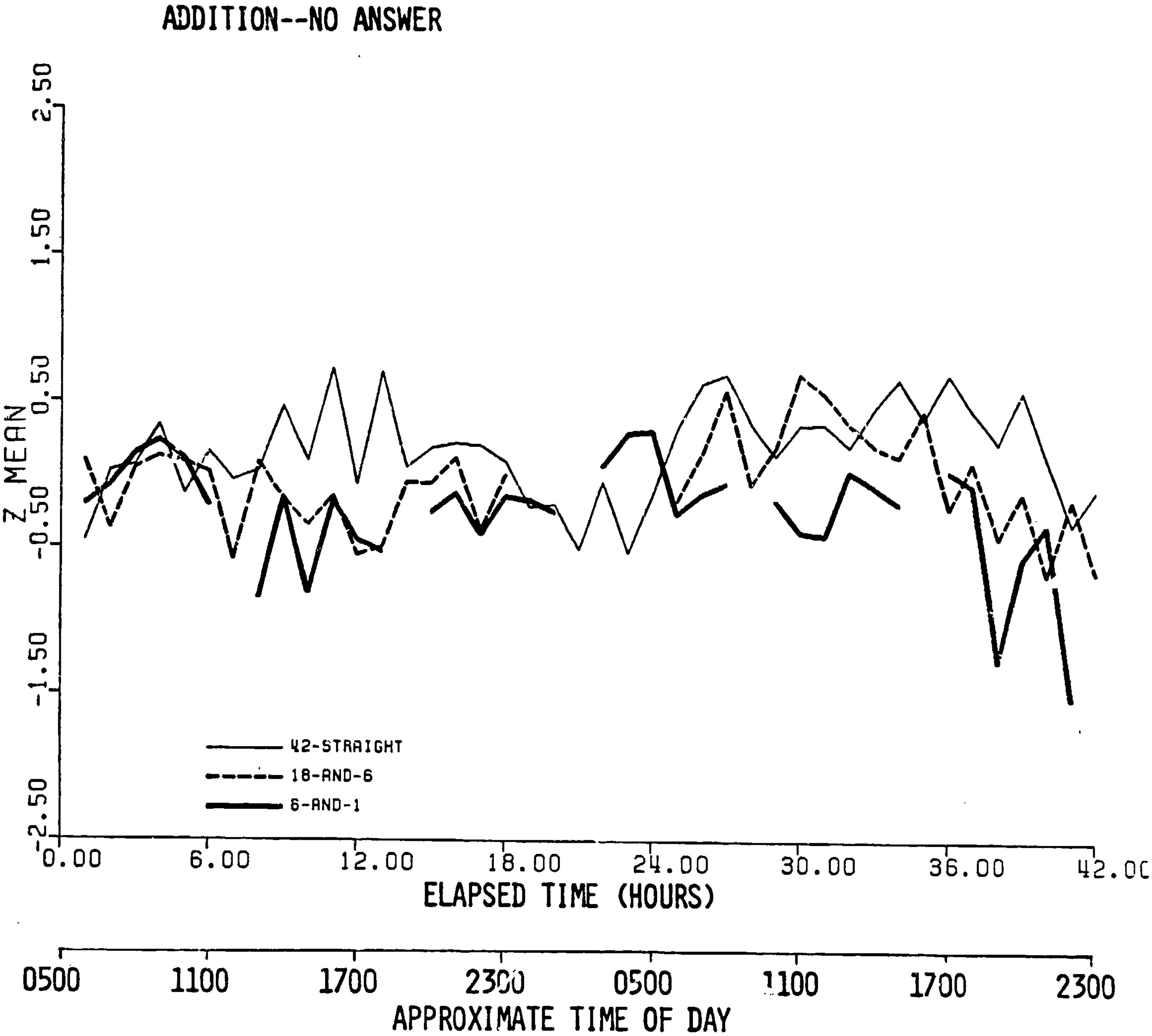



FIG. 8A Hourly means of normalized numbers of failures to respond (no answer) during the addition task for the three experimental groups. Group data are plotted with the mean z-score of the first 6 hours set to the 0 level on the ordinate. Means were derived from z-scores for the entire data of each subject.

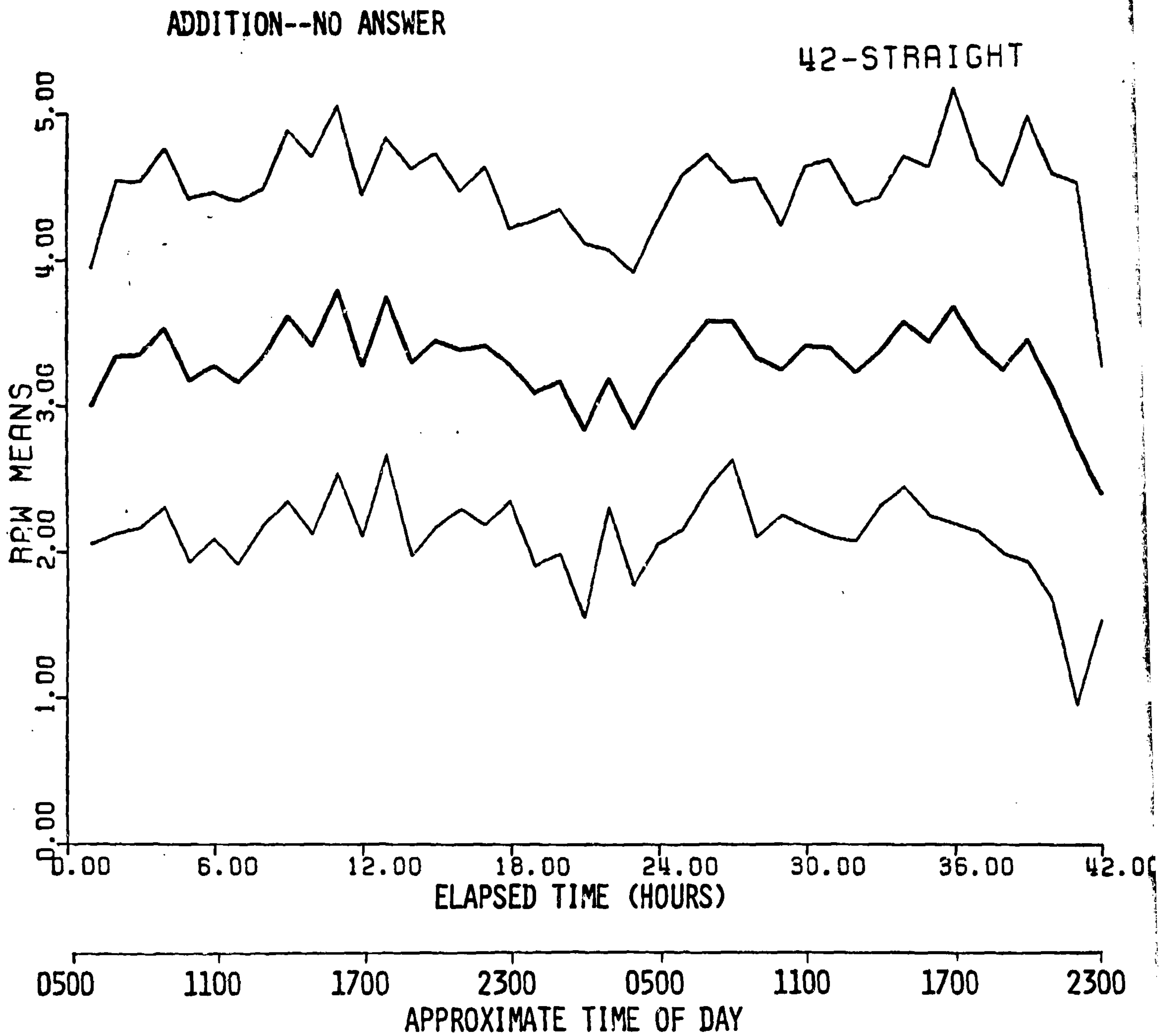



FIG. 8B Hourly means of the number of failures to respond (no answer) during the addition task for the 42-straight group. Also plotted are 95% confidence limits.

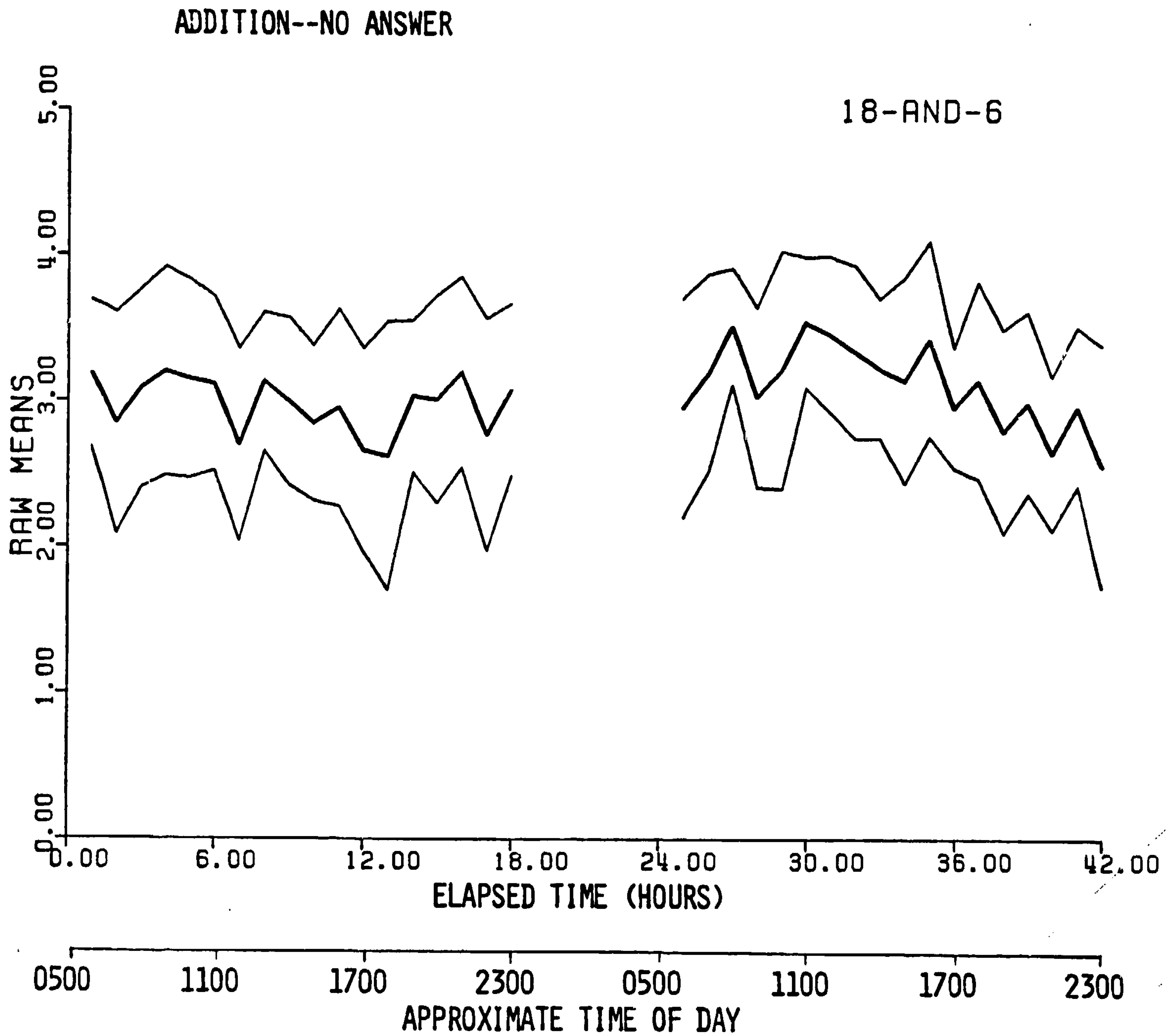



FIG. 8C Hourly means of the number of failures to respond (no answer) during the addition task for the 18-and-6 group. Also plotted are 95% confidence limits.

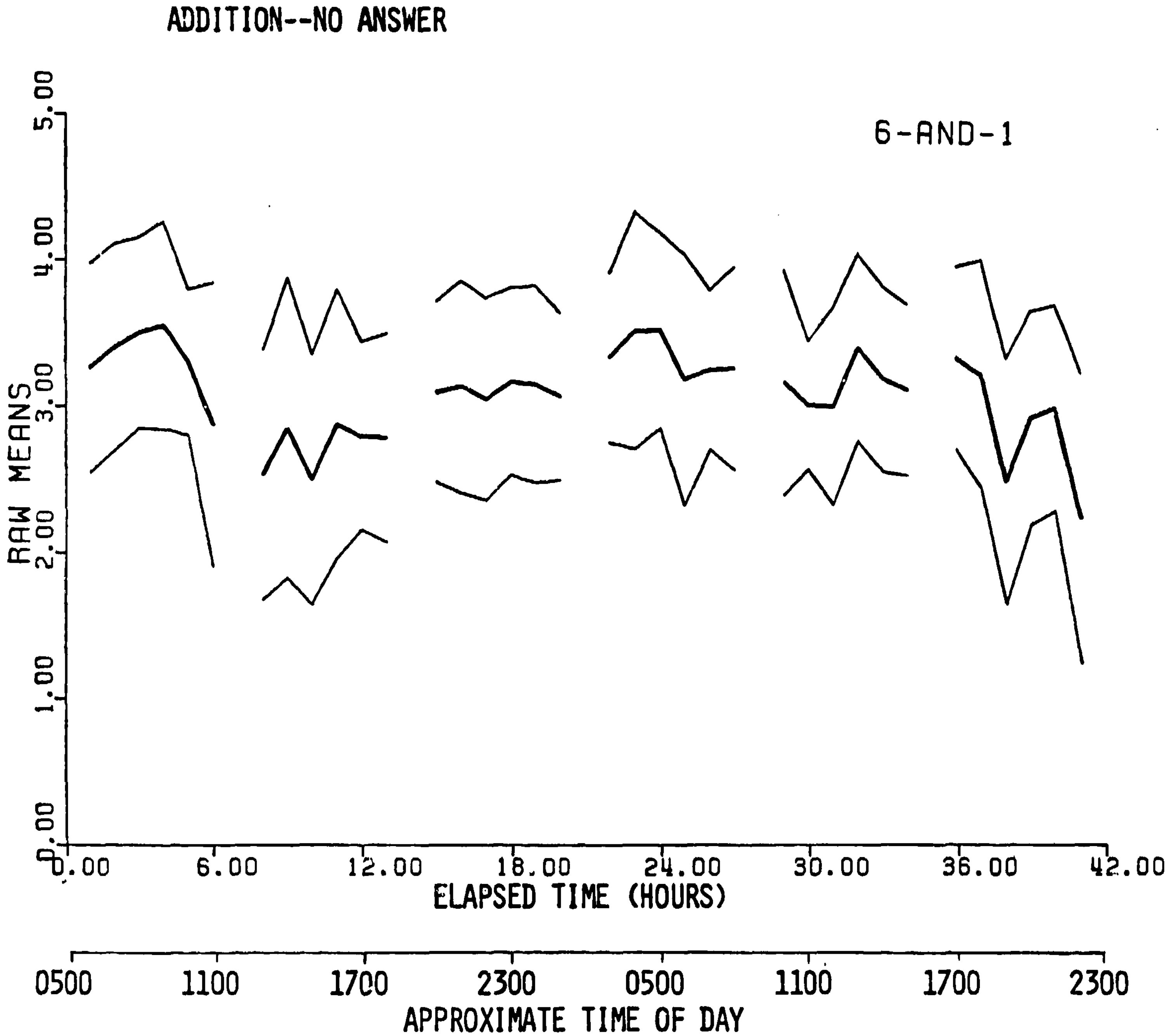



FIG 8D Hourly means of the number of failures to respond (no answer) during the addition task for the 6-and-1 group. Also plotted are 95% confidence limits.

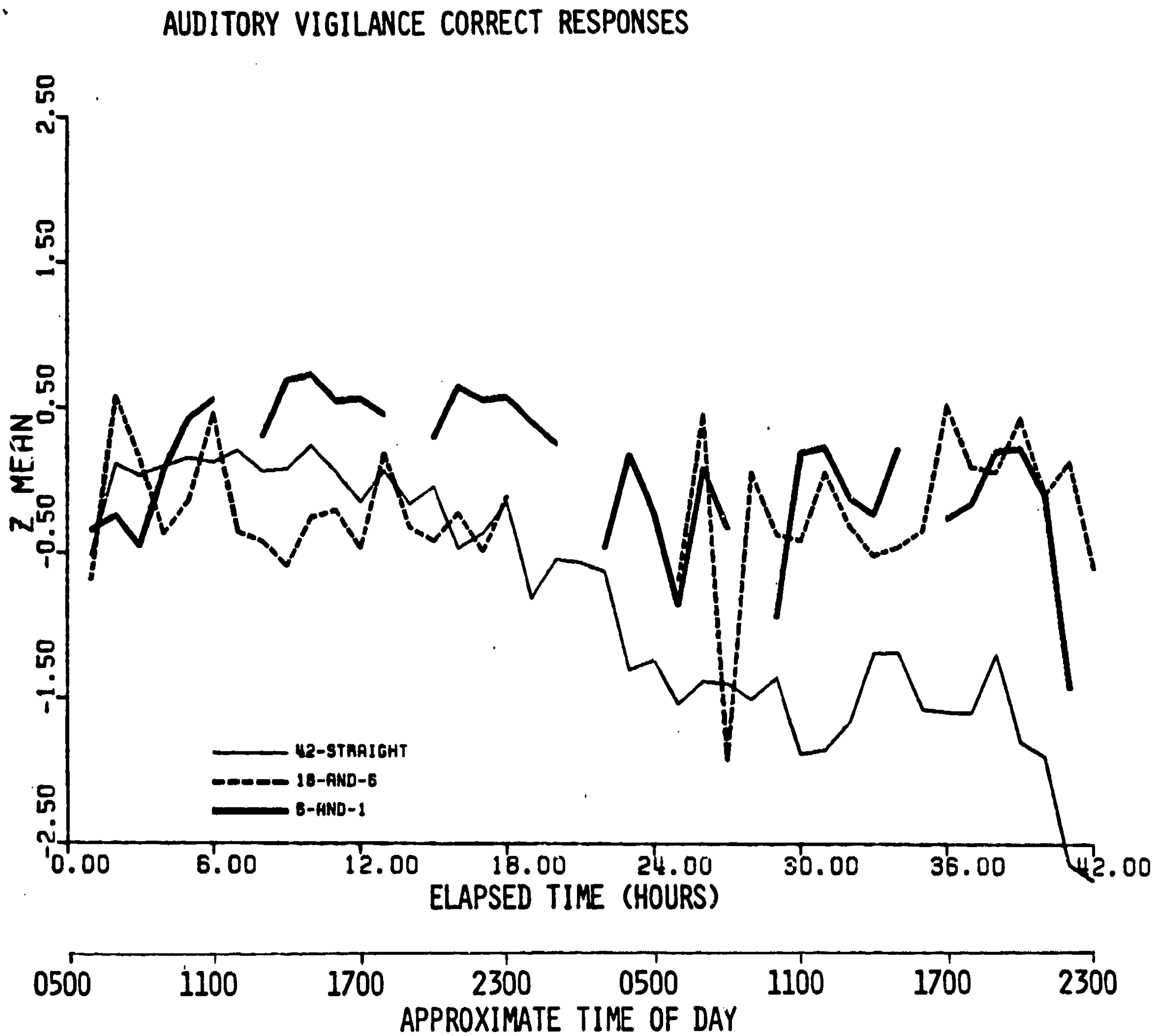



FIG. 9A Hourly means of normalized auditory vigilance performance for the three experimental groups. Group data are plotted with the mean z-score of the first 6 hours set to the 0 level on the ordinate. Means were derived from z-scores for the entire data of each subject.

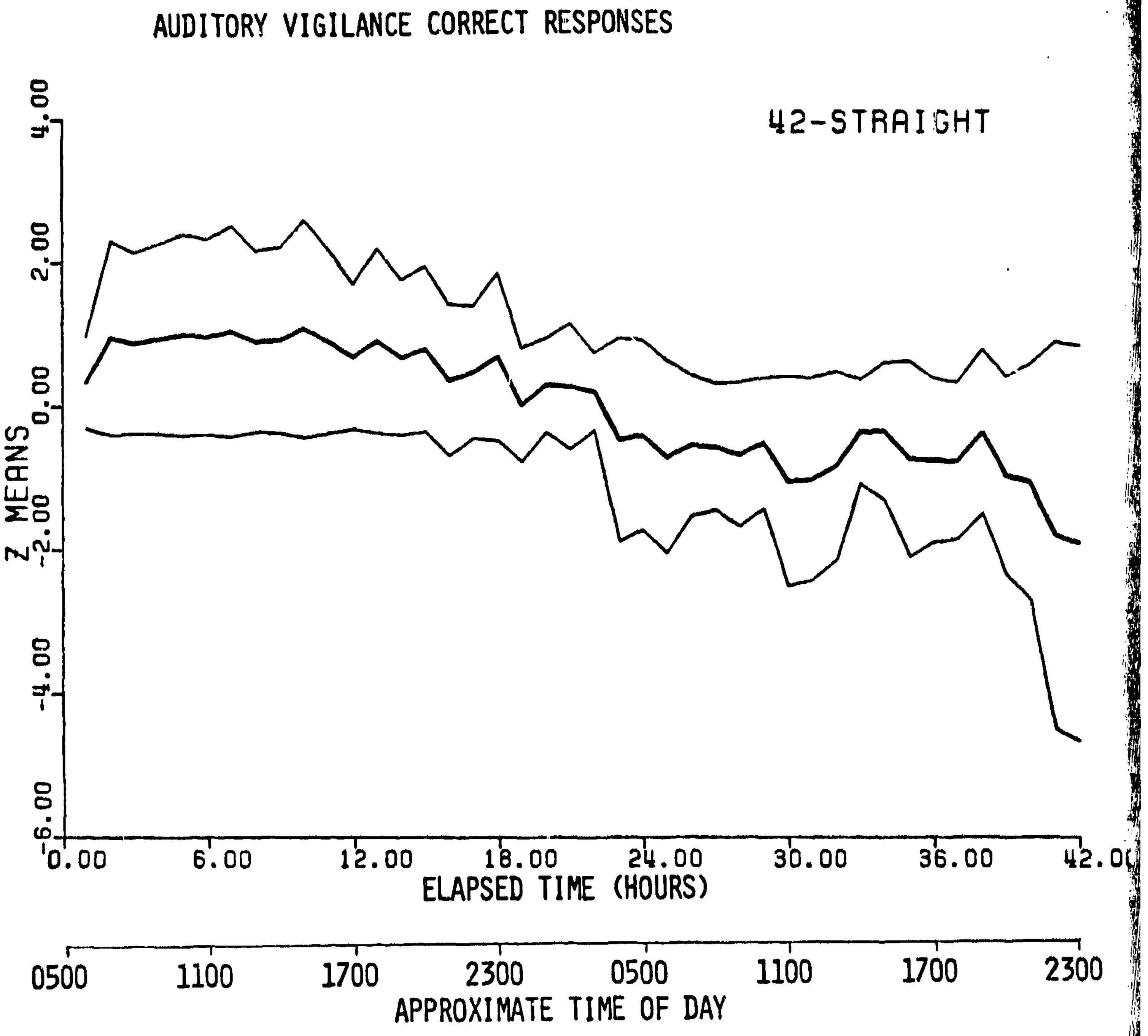



FIG. 9B Hourly means of normalized auditory vigilance performance for the 42-straight group. Means were derived from z-scores for the entire data of each subject. Also plotted are 95% confidence limits.

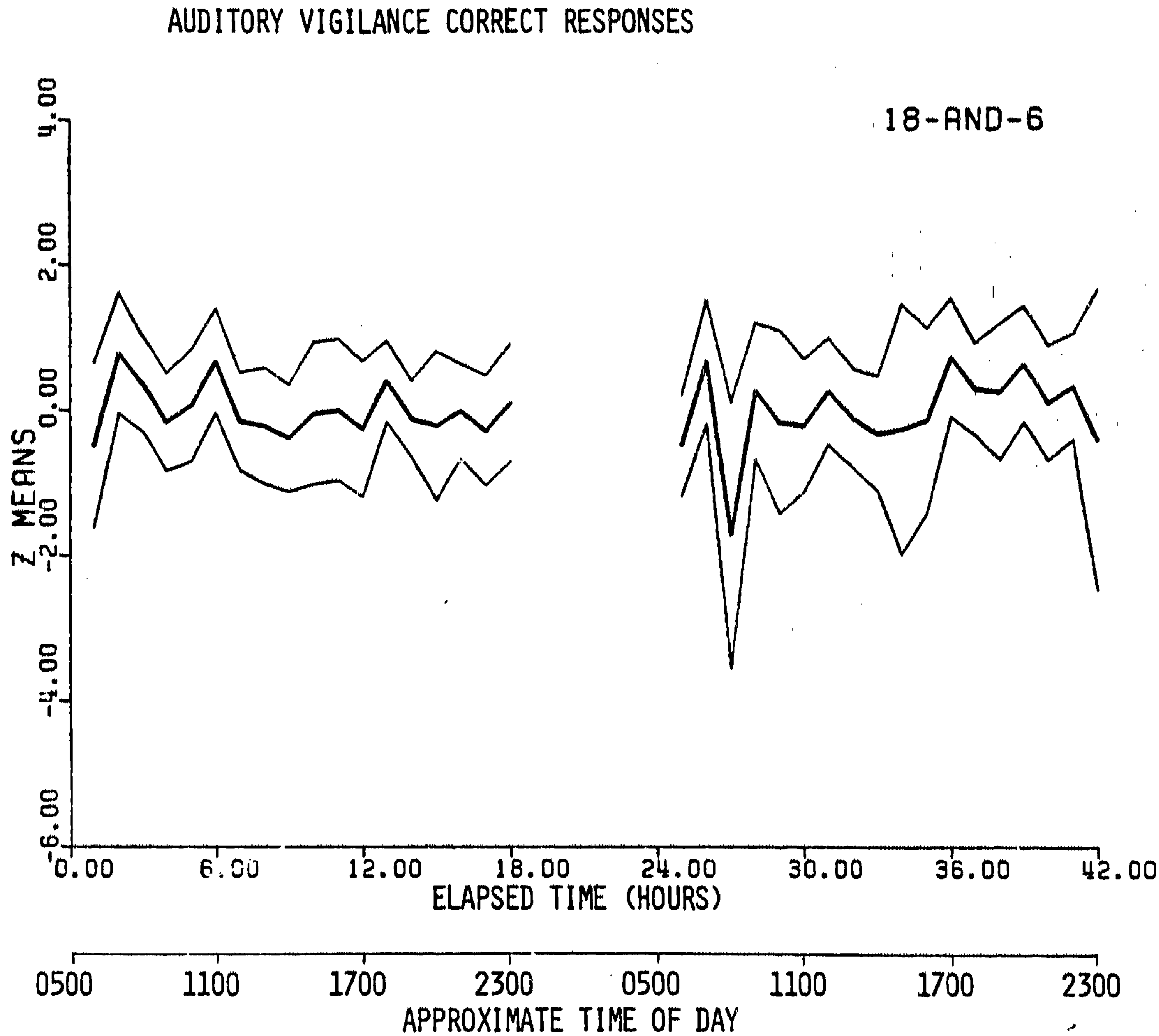



FIG. 9c Hourly means of normalized auditory vigilance performance for the 18-and-6 group. Means were derived from z-scores for the entire data of each subject. Also plotted are 95% confidence limits.

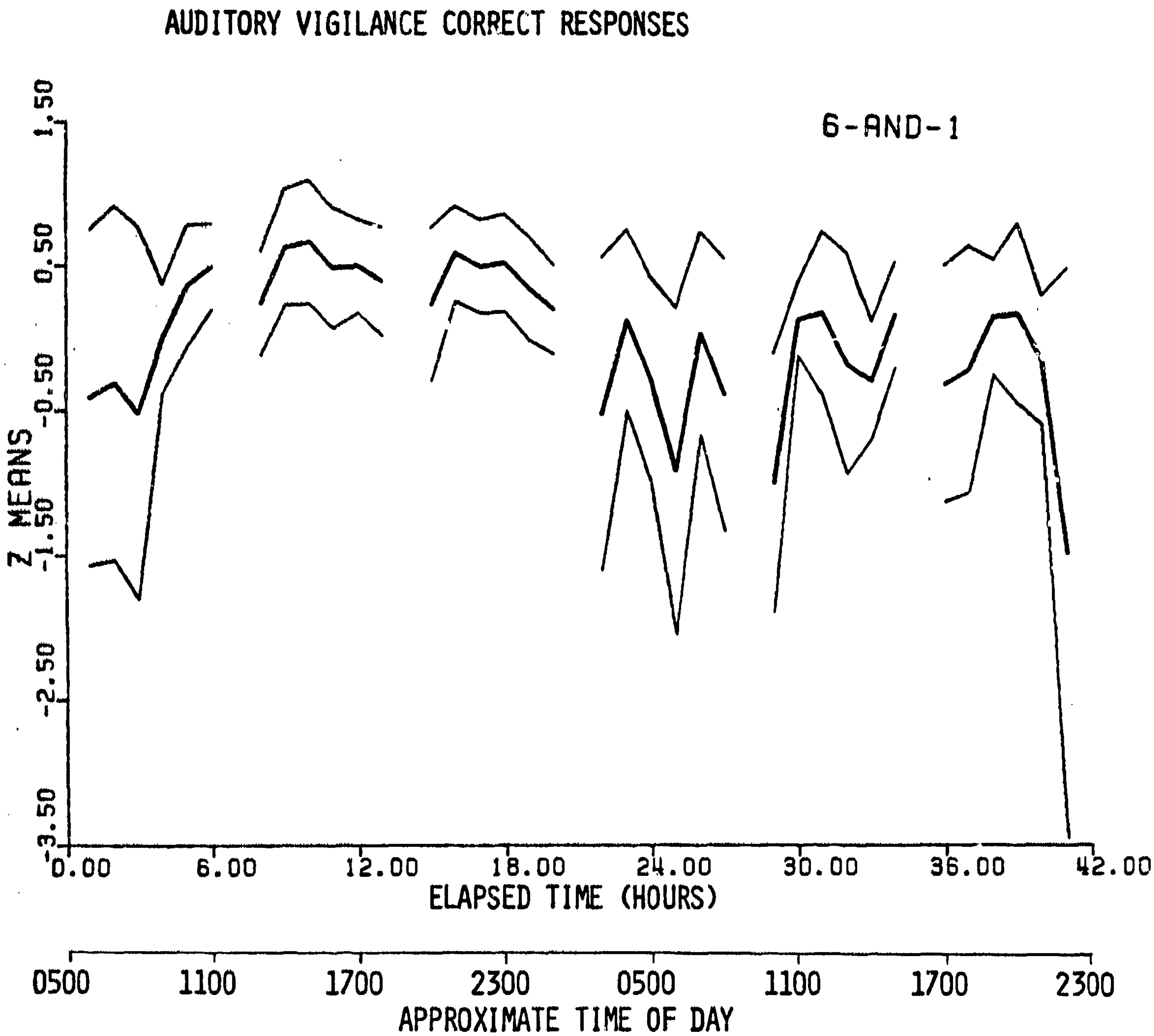



FIG. 9D Hourly means of normalized auditory vigilance performance for the 6-and-1 group. Means were derived from z-scores for the entire data of each subject. Also plotted are 95% confidence limits.

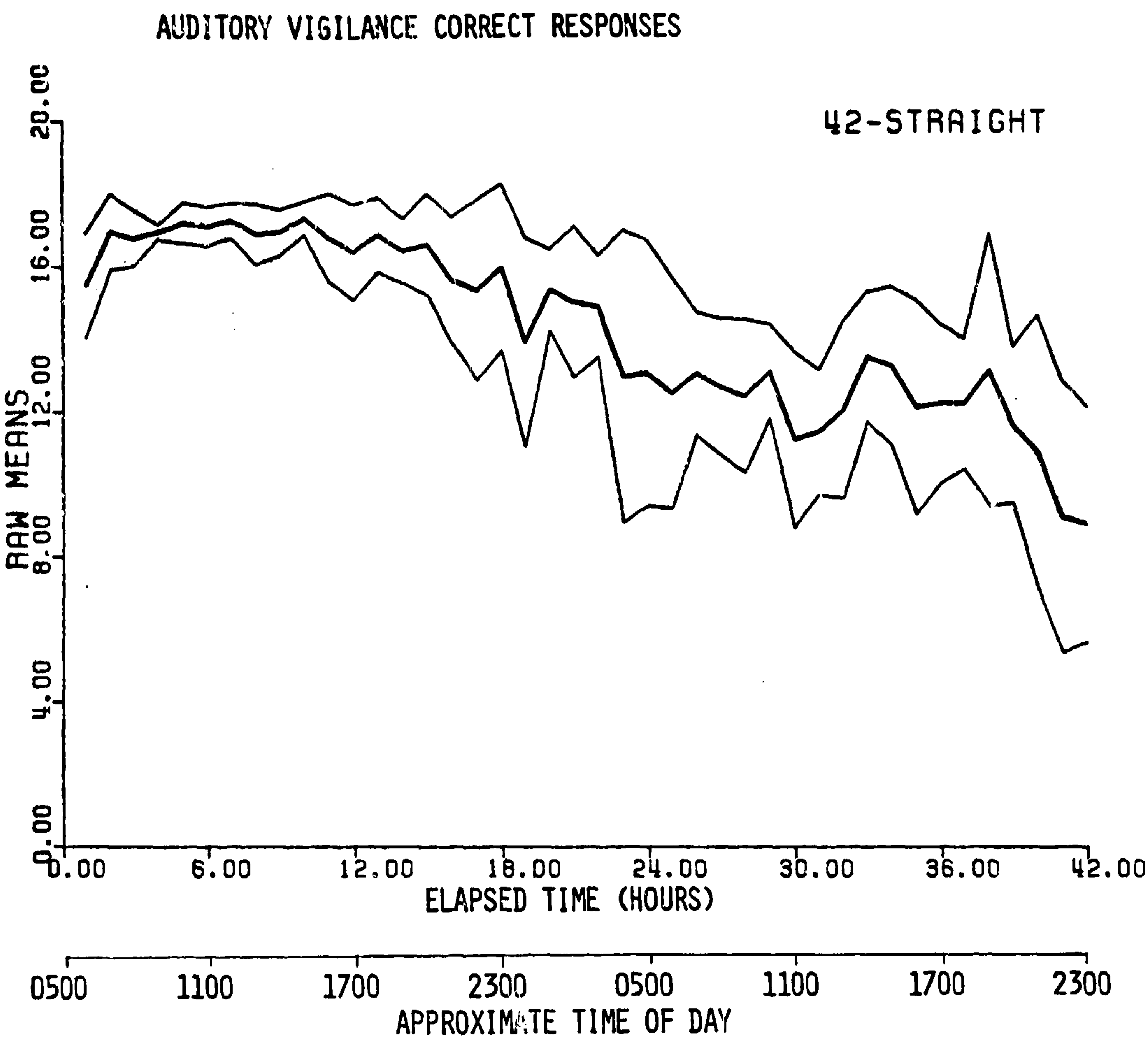



FIG. 9E Hourly means of auditory vigilance performance for the 42-straight group. Also plotted are 95% confidence limits.

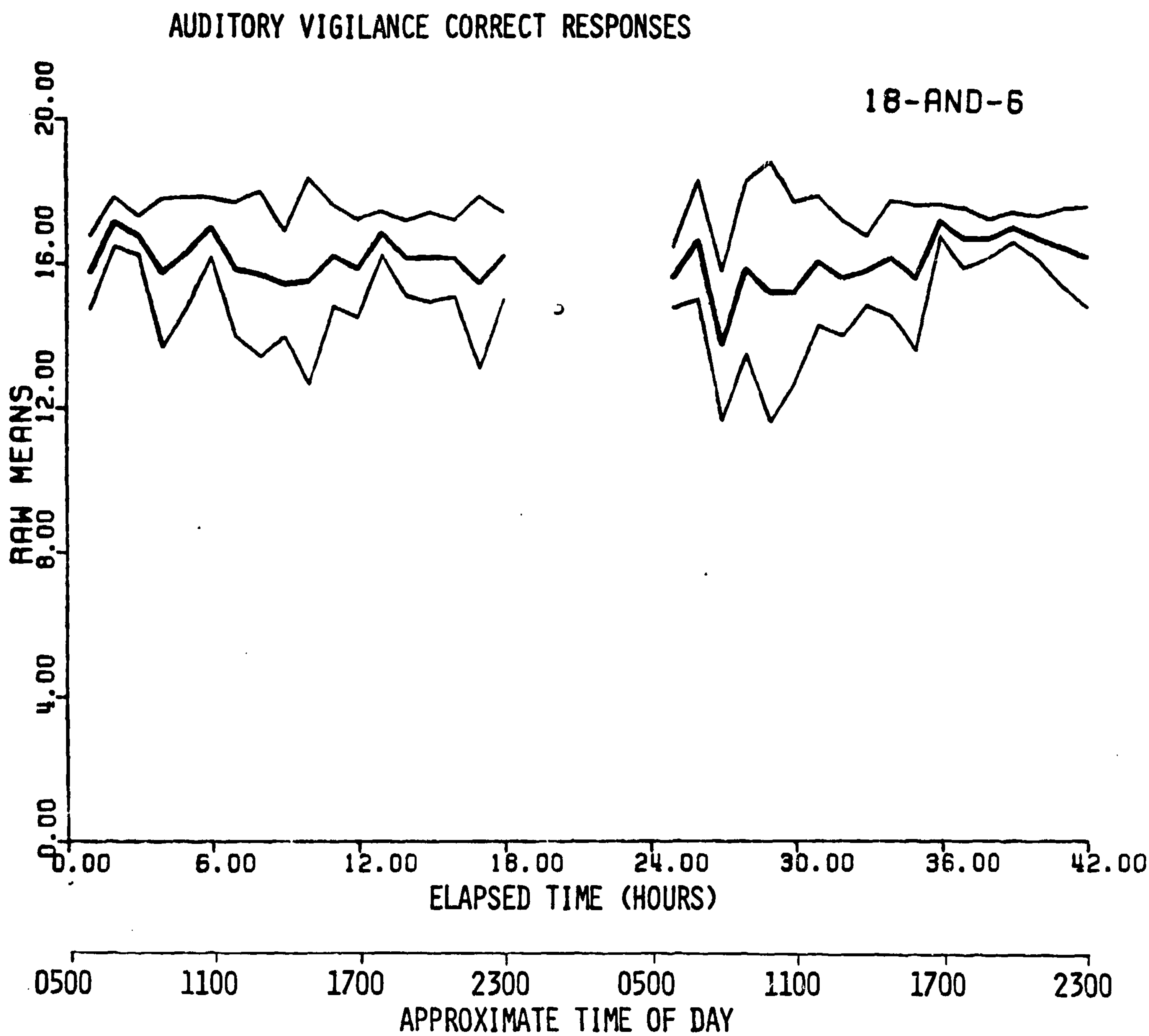



FIG. 9F Hourly means of auditory vigilance performance for the 18-and-6 group. Also plotted are 95% confidence limits.

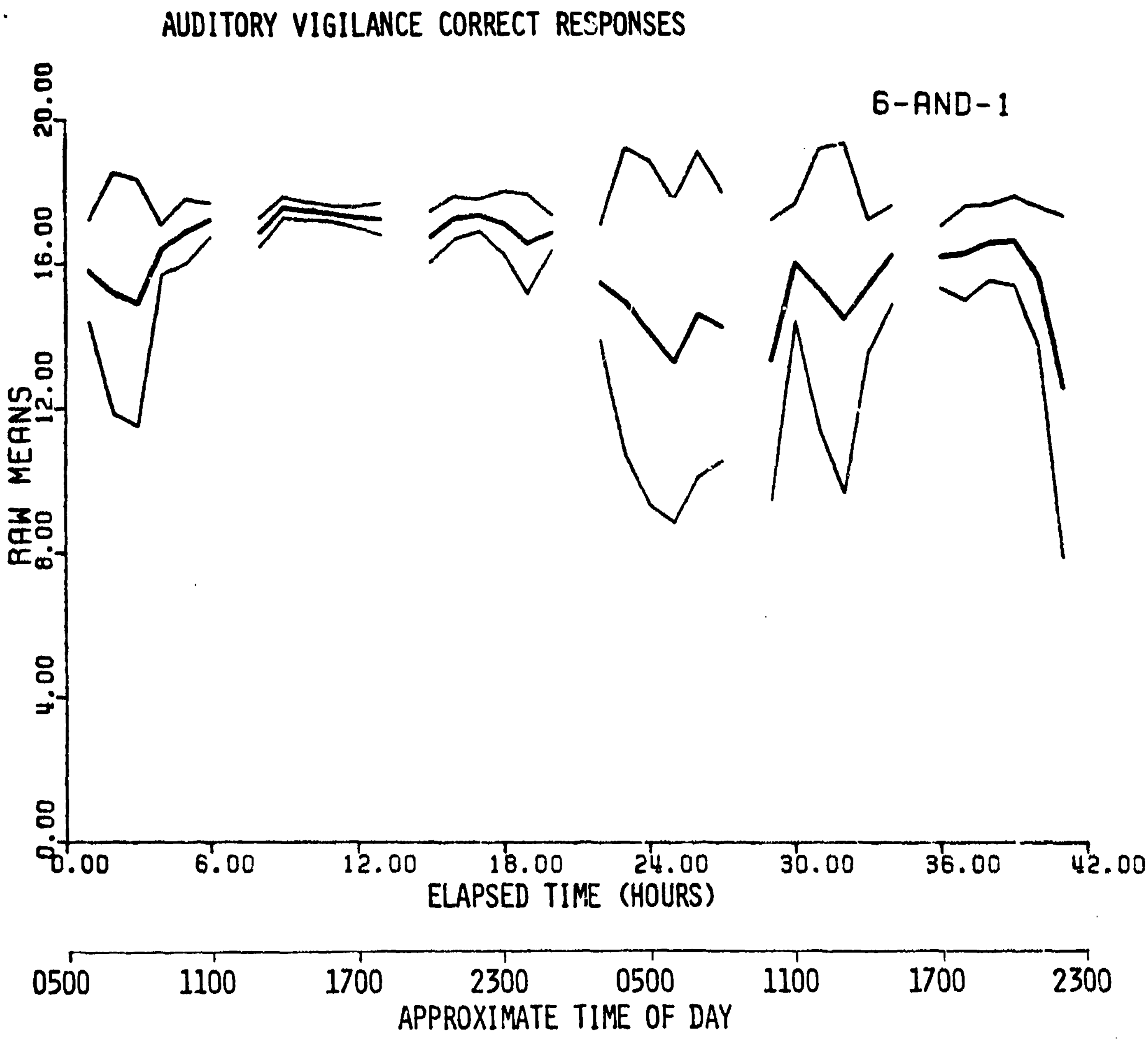



FIG. 9G Hourly means of auditory vigilance performance for the 6-and-1 group. Also plotted are 95% confidence limits.

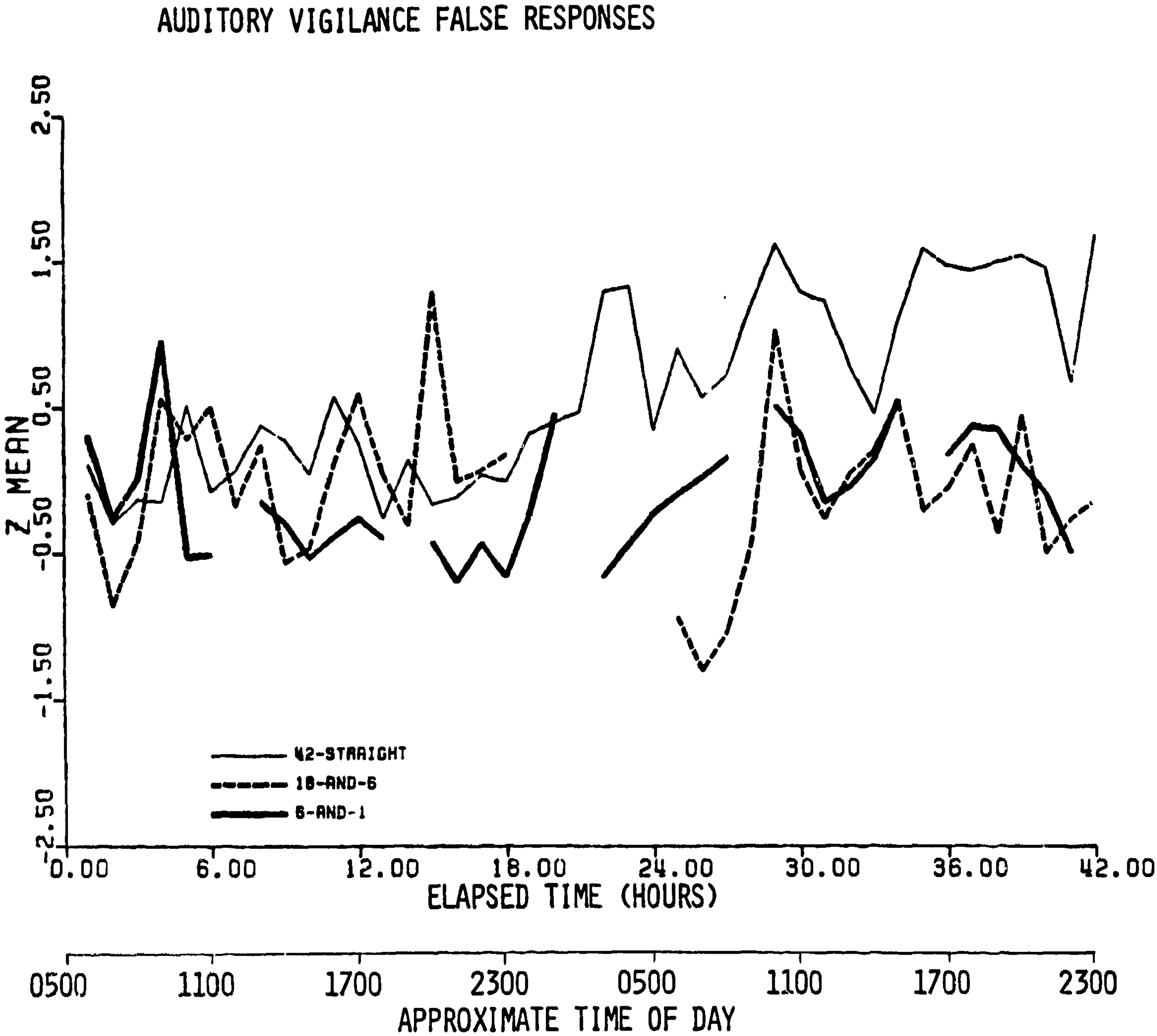



FIG. 10A Hourly means of normalized numbers of false responses for the three experimental groups. Group data are plotted with the mean z-score of the first 6 hours set to the 0 level on the ordinate. Means were derived from z-scores for the entire data of each subject.

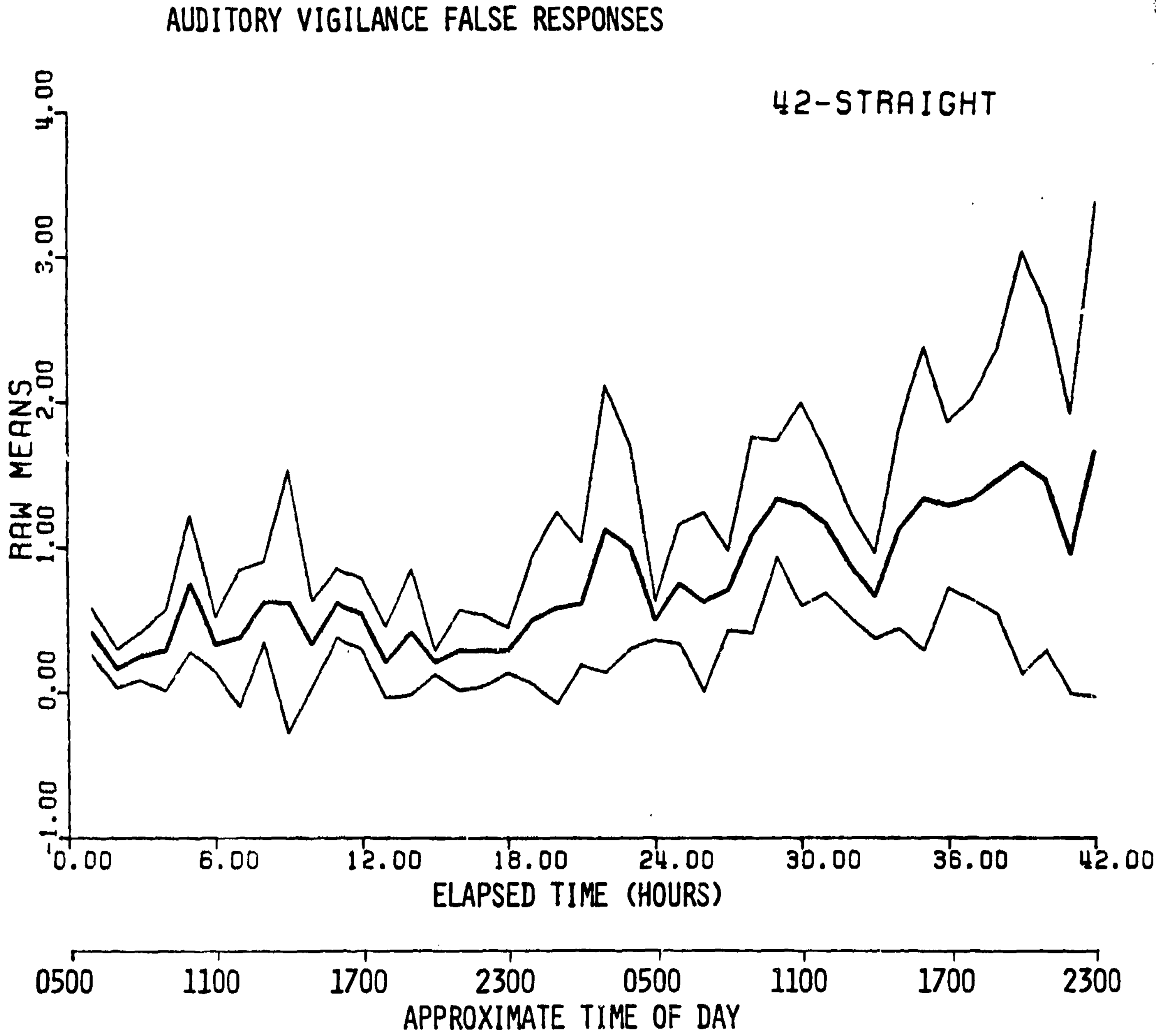



FIG. 10B Hourly means of numbers of false responses for the 42-straight group. Also plotted are 95% confidence limits.

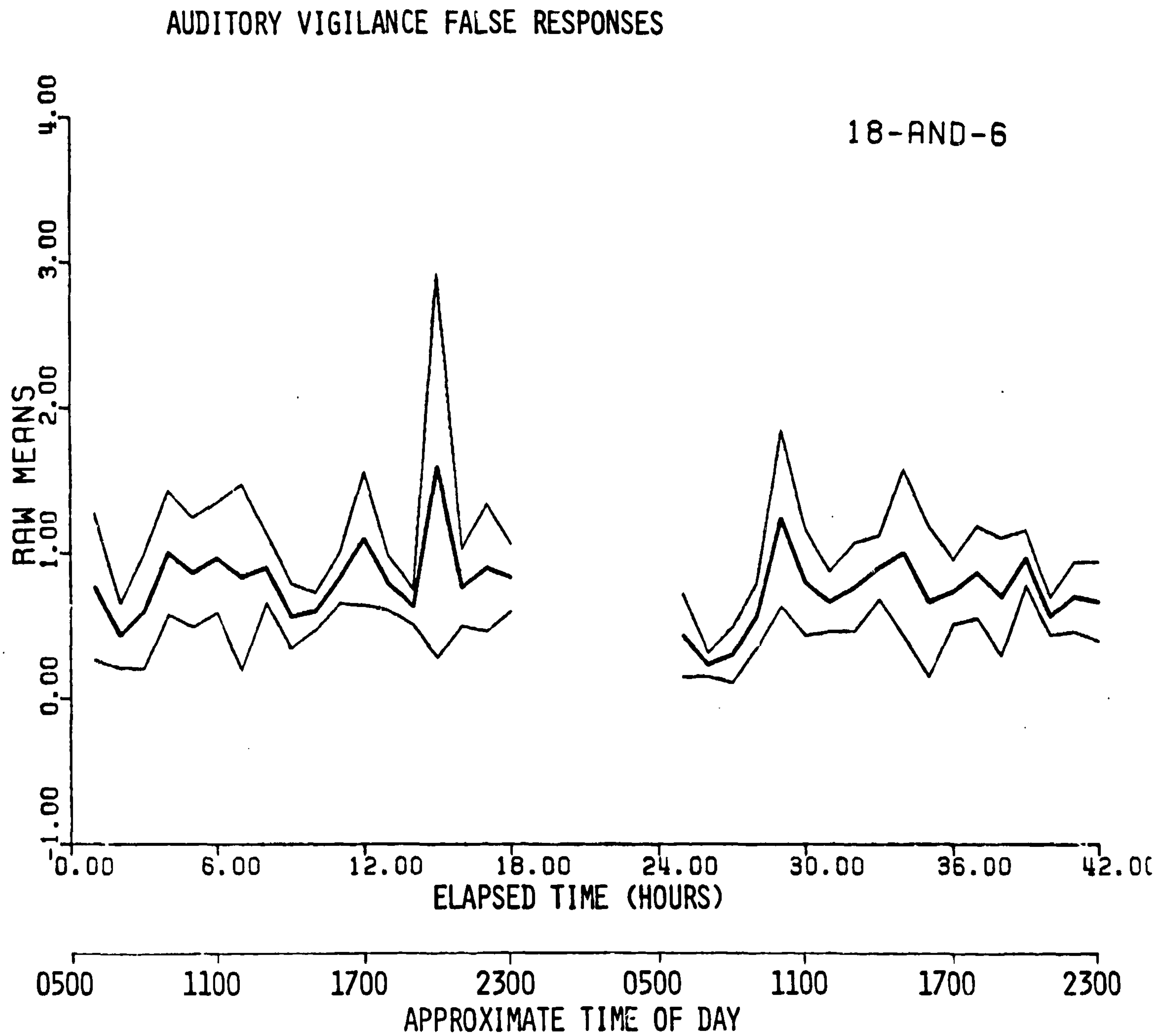



FIG. 10C Hourly means of numbers of auditory vigilance false responses for the 18-and-6 group. Also plotted are 95% confidence limits.

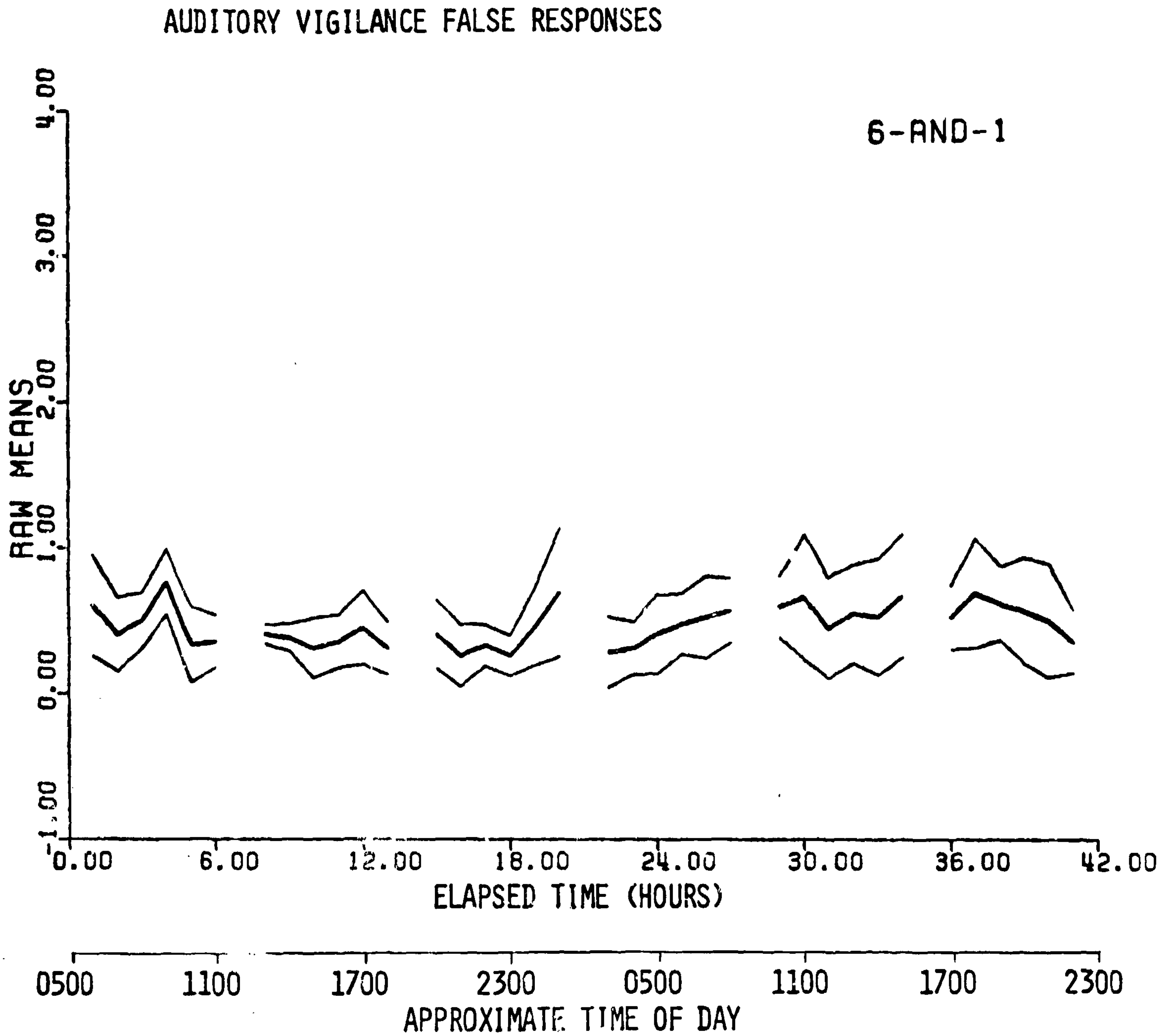



FIG. 10D Hourly means of numbers of auditory vigilance false responses for the 6-and-1 group. Also plotted are 95% confidence limits.

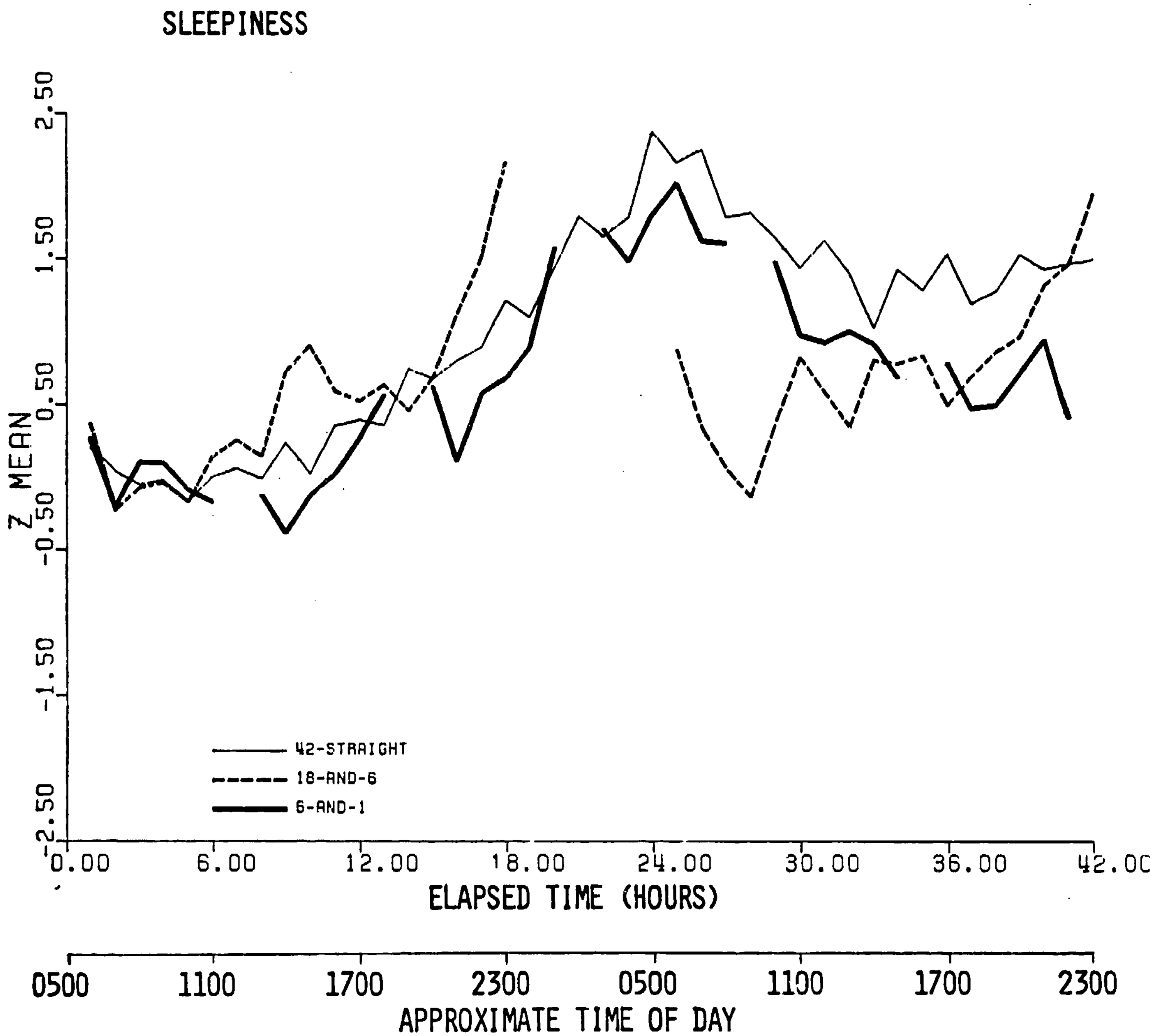



FIG. 11A Hourly means of normalized subjective sleepiness estimates for the three experimental groups. Group data are plotted with the mean z-score of the first 6 hours set to the 0 level on the ordinate. Means were derived from z-scores for the entire data of each subject.

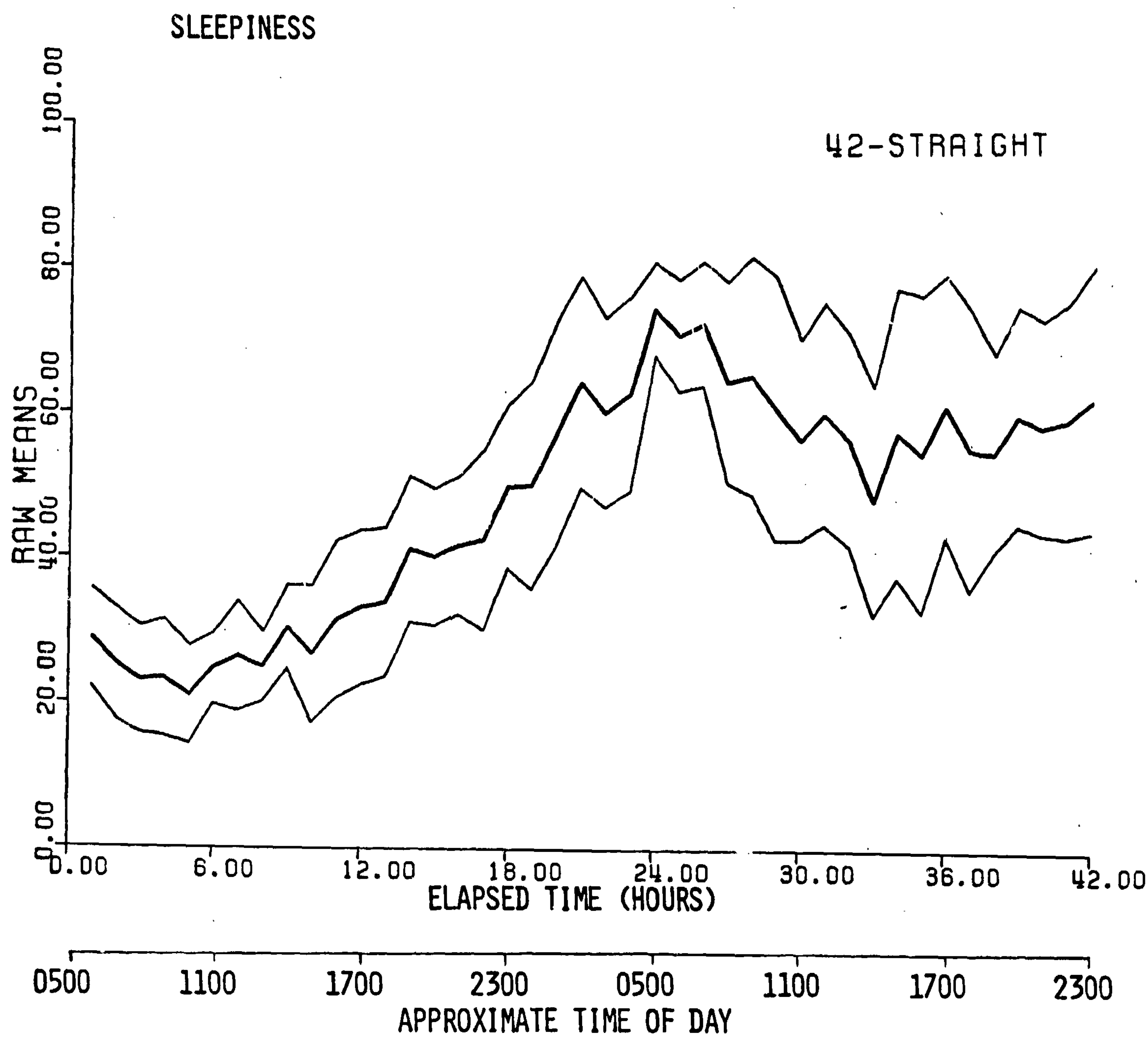



FIG. 11B Hourly means of subjective sleepiness for the 42-straight group. Also plotted are 95% confidence limits.

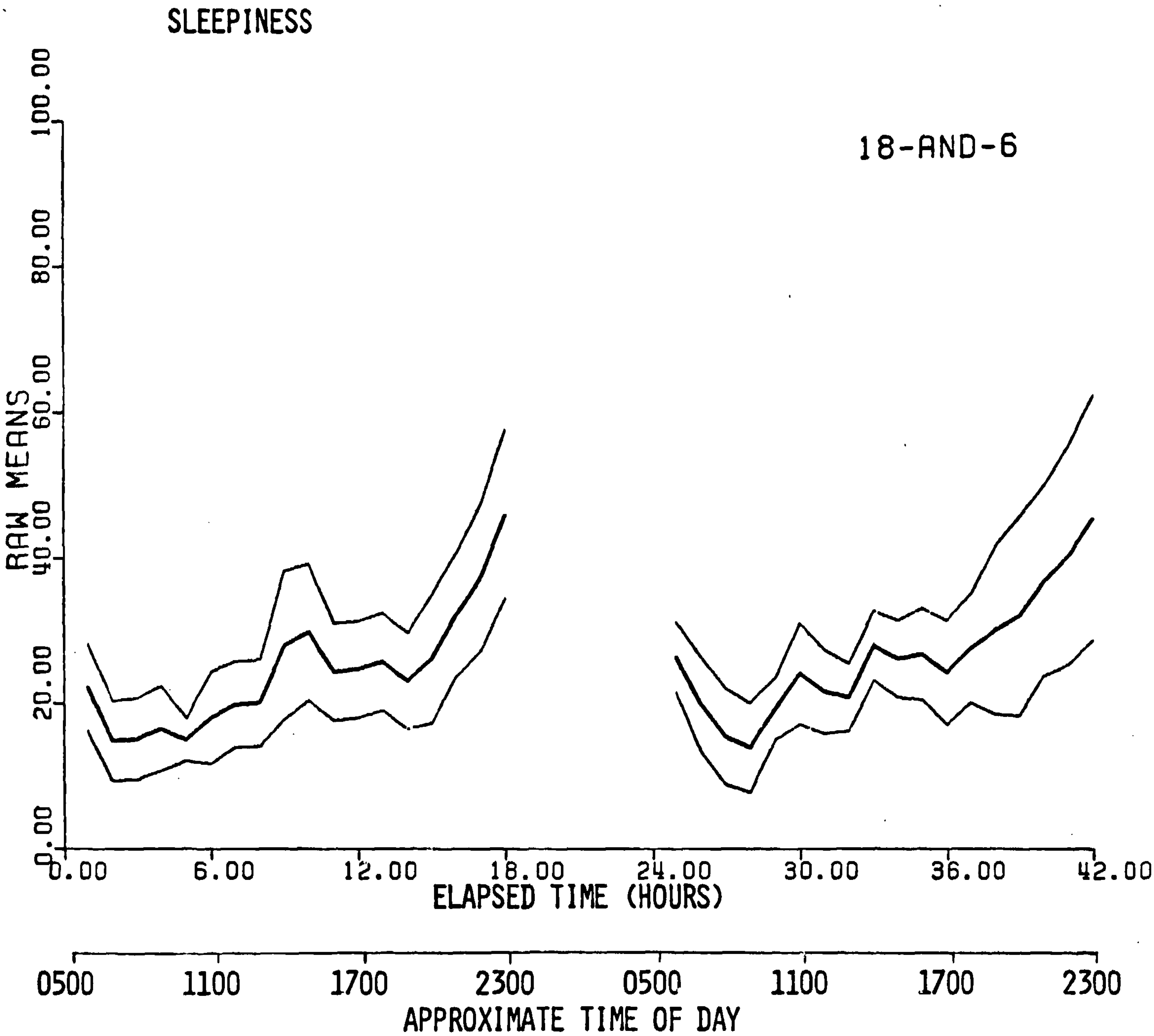



FIG. 11c Hourly means of subjective sleepiness for the 18-and-6 group. Also plotted are 95% confidence limits.

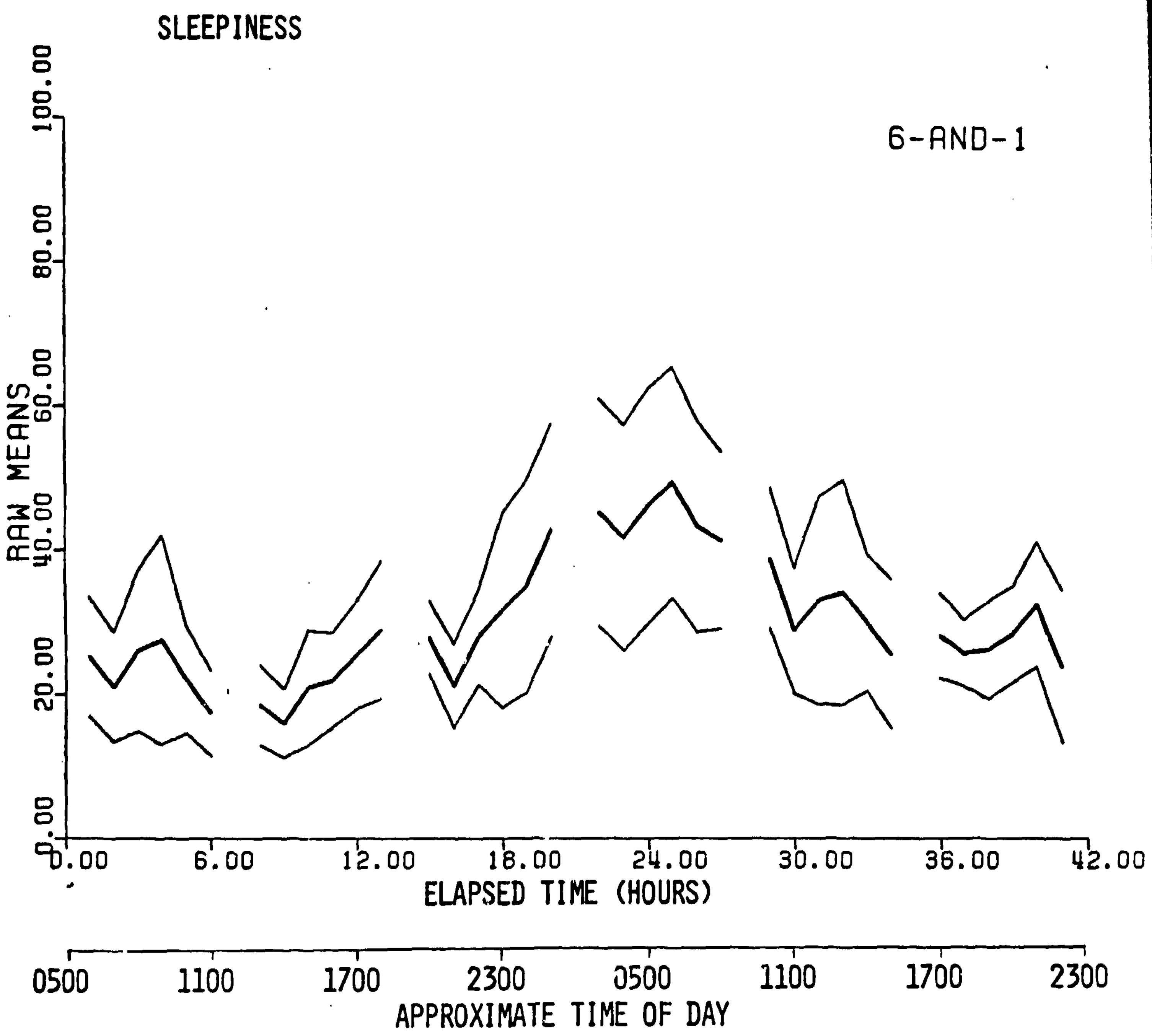



FIG. 11D Hourly means of subjective sleepiness for the 6-and-1 group. Also plotted are 95% confidence limits.

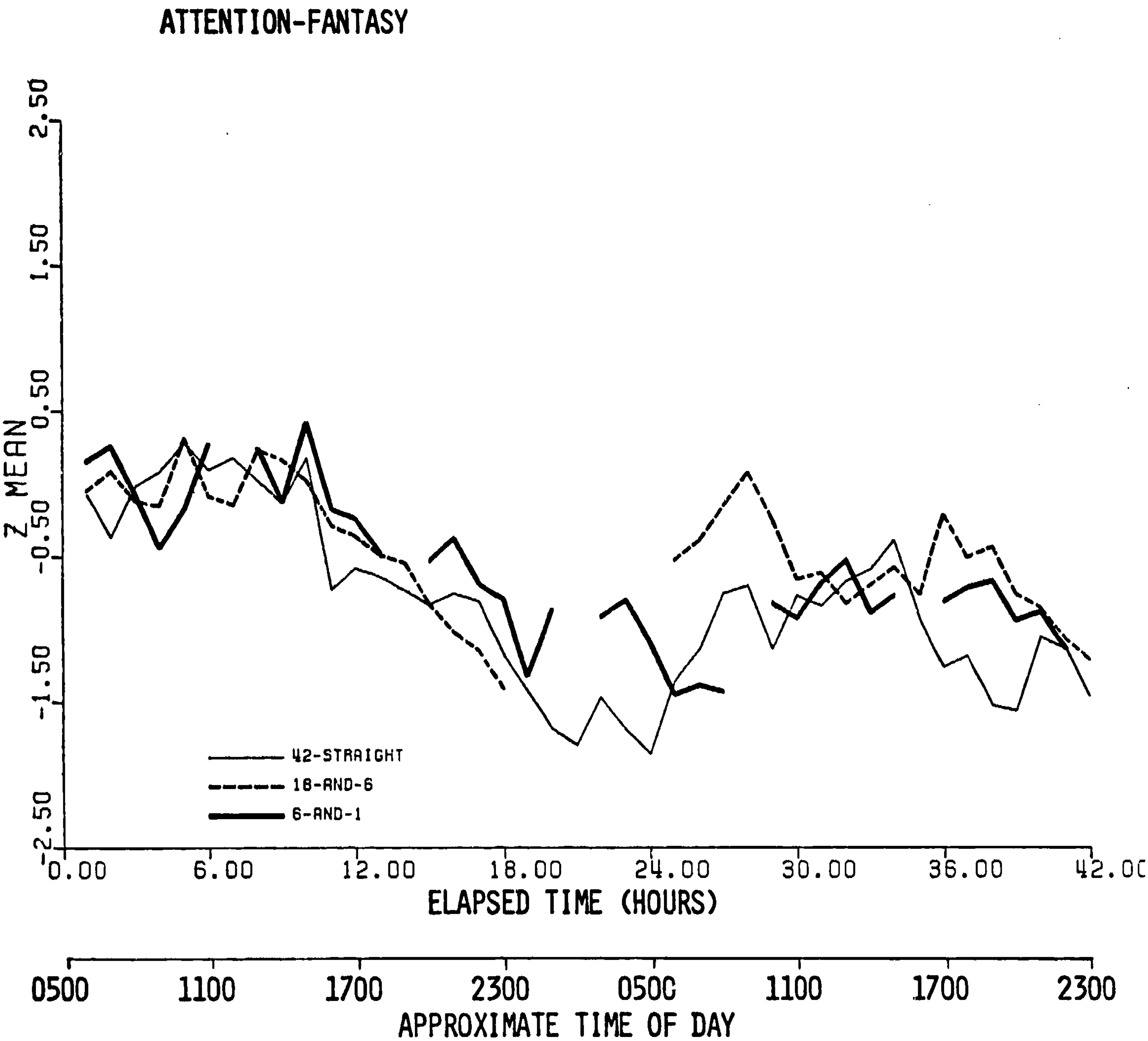



FIG. 12A Hourly means of normalized attention-fantasy scale estimates for the three experimental groups. Group data are plotted with the mean z-score of the first 6 hours set to the 0 level on the ordinate. Means were derived from z-scores for the entire data of each subject.

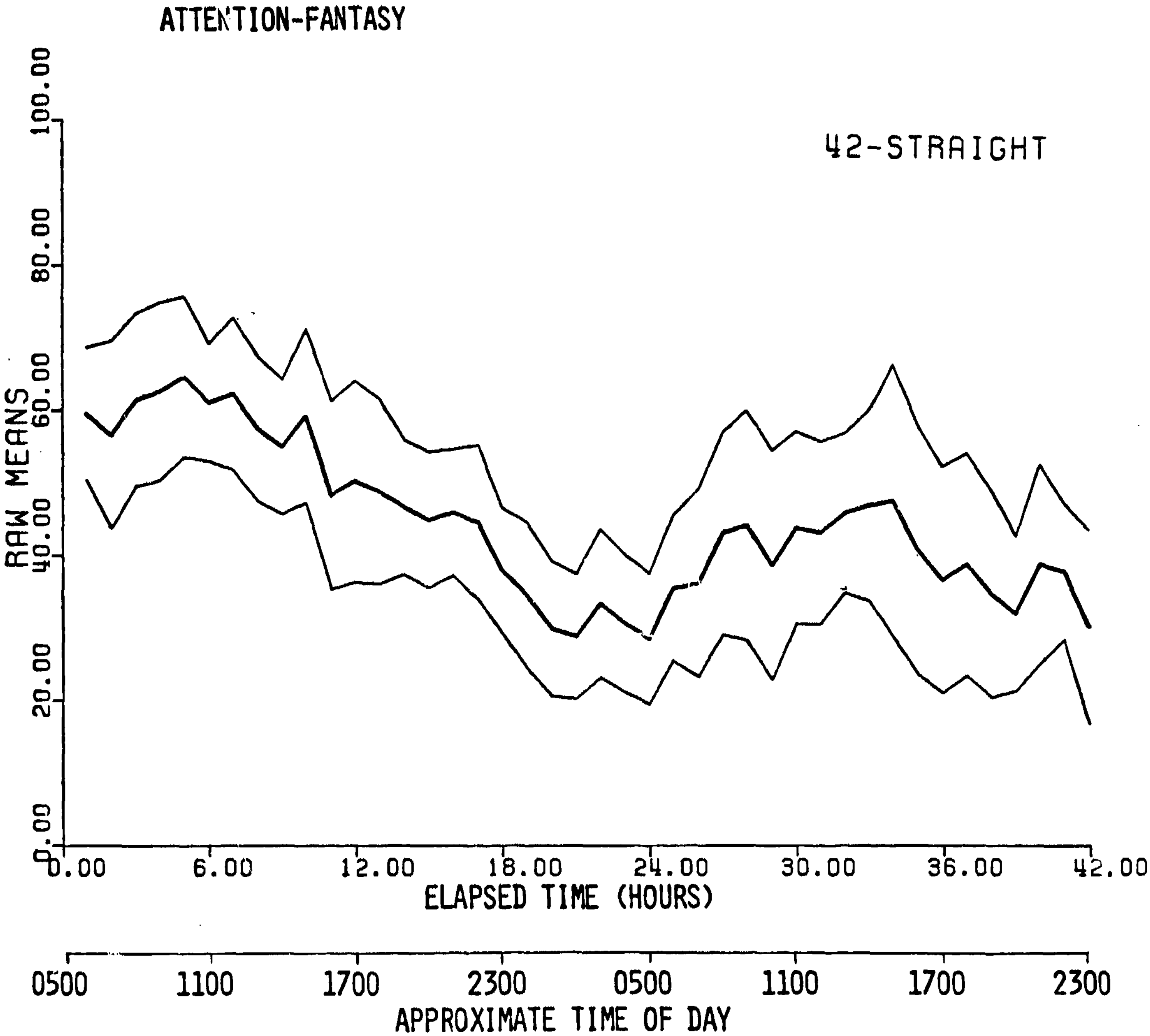



FIG. 12B Hourly means of attention-fantasy scale for the 42-straight group. Also plotted are 95% confidence limits.

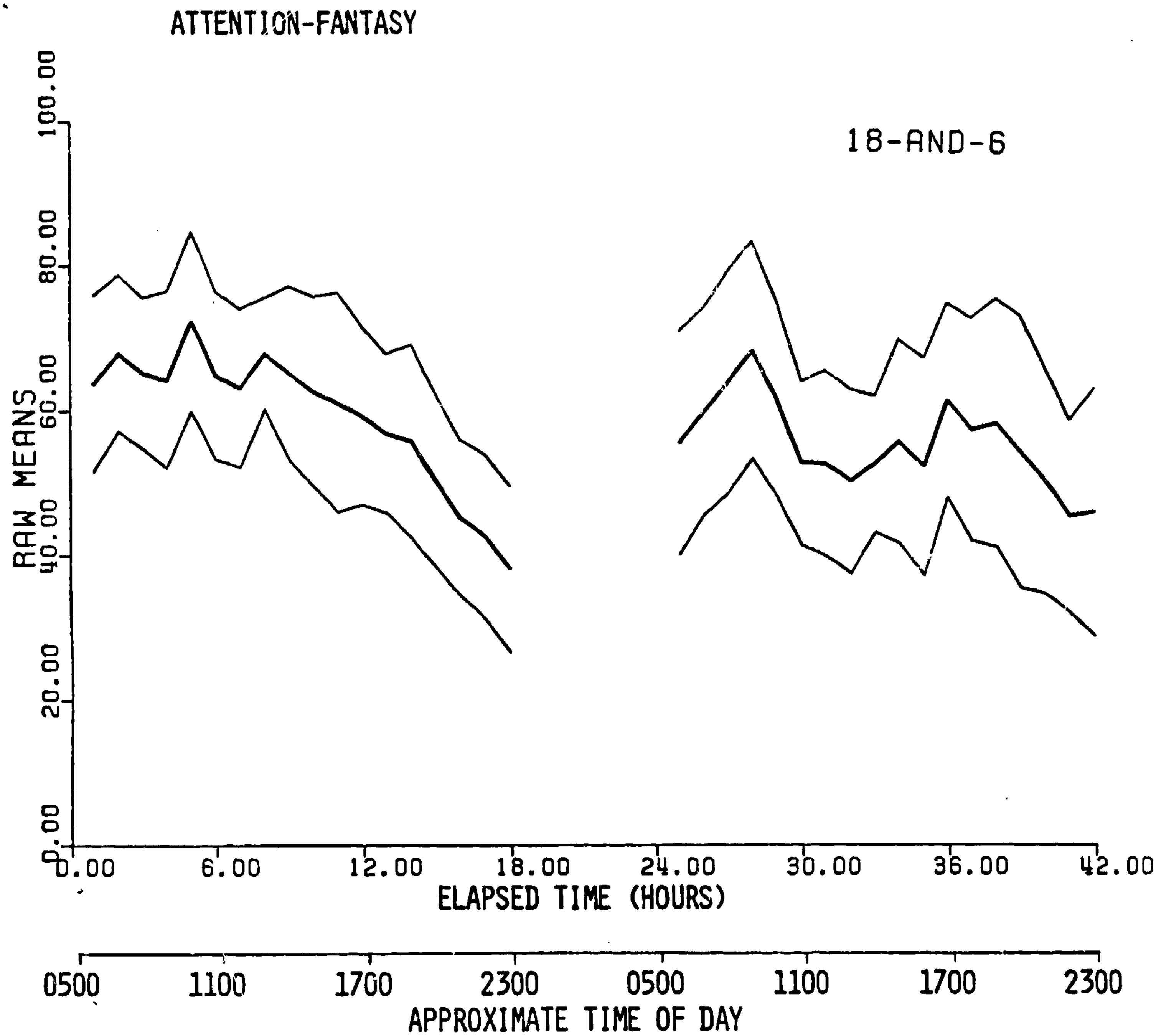



FIG. 12C Hourly means of attention-fantasy scale for the 18-and-6 group. Also plotted are 95% confidence limits.

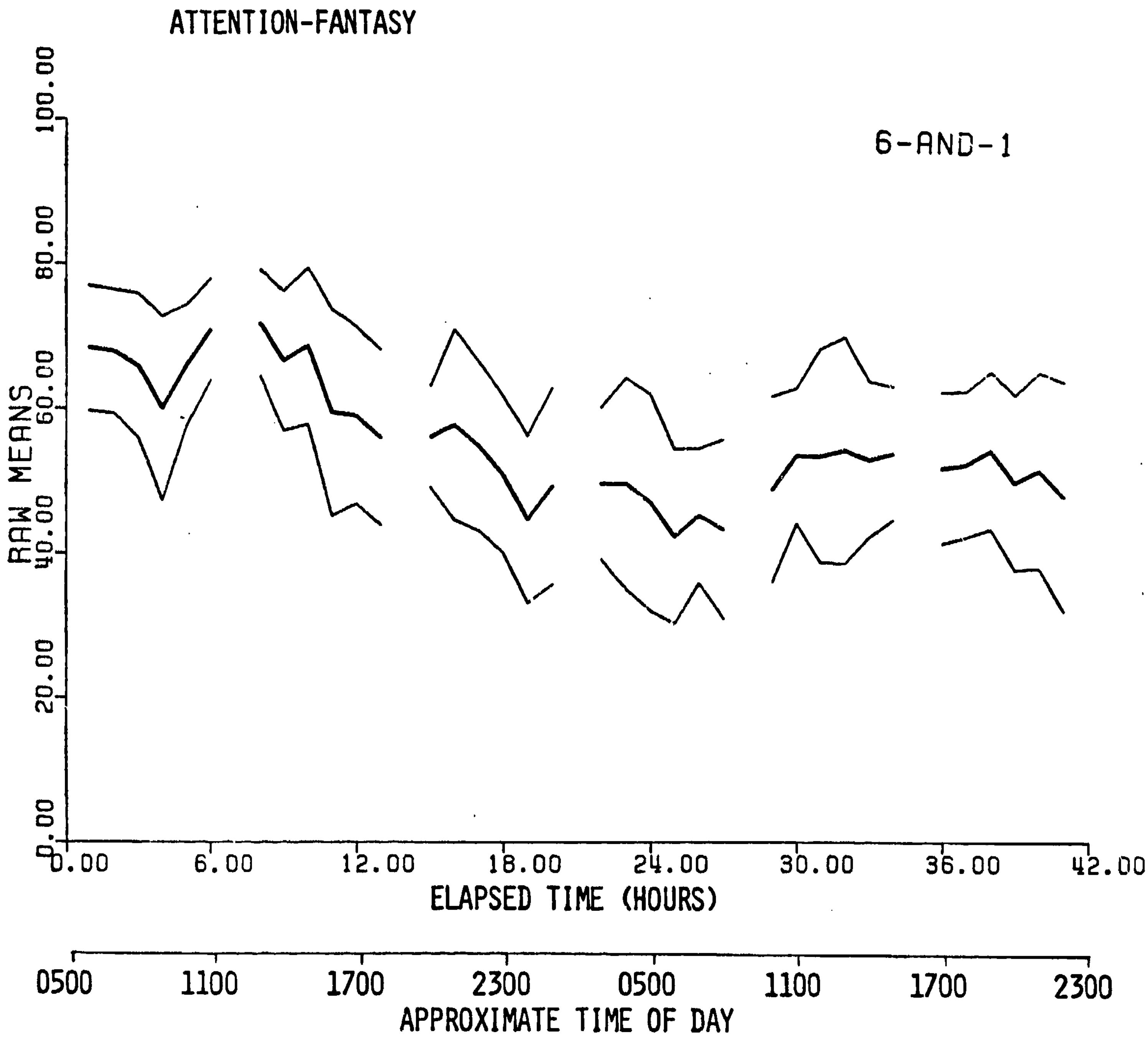



FIG. 12D Hourly means of attention-fantasy scale for the 6-and-1 group. Also plotted are 95% confidence limits.

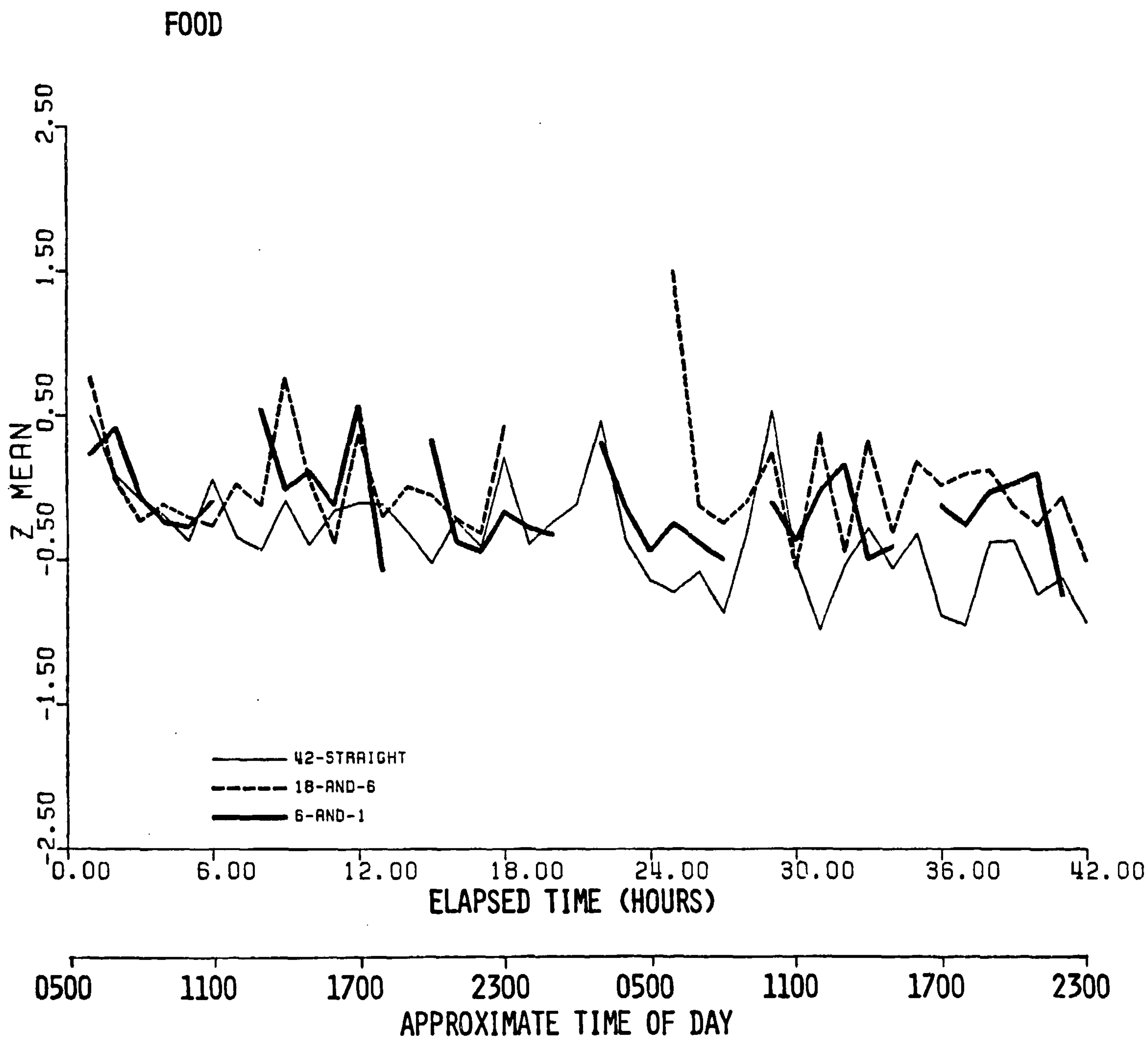



FIG. 13A Hourly means of normalized estimates of food consumed for the three experimental groups. Group data are plotted with the mean z-score of the first 6 hours set to the 0 level on the ordinate. Means were derived from z-scores for the entire data of each subject.

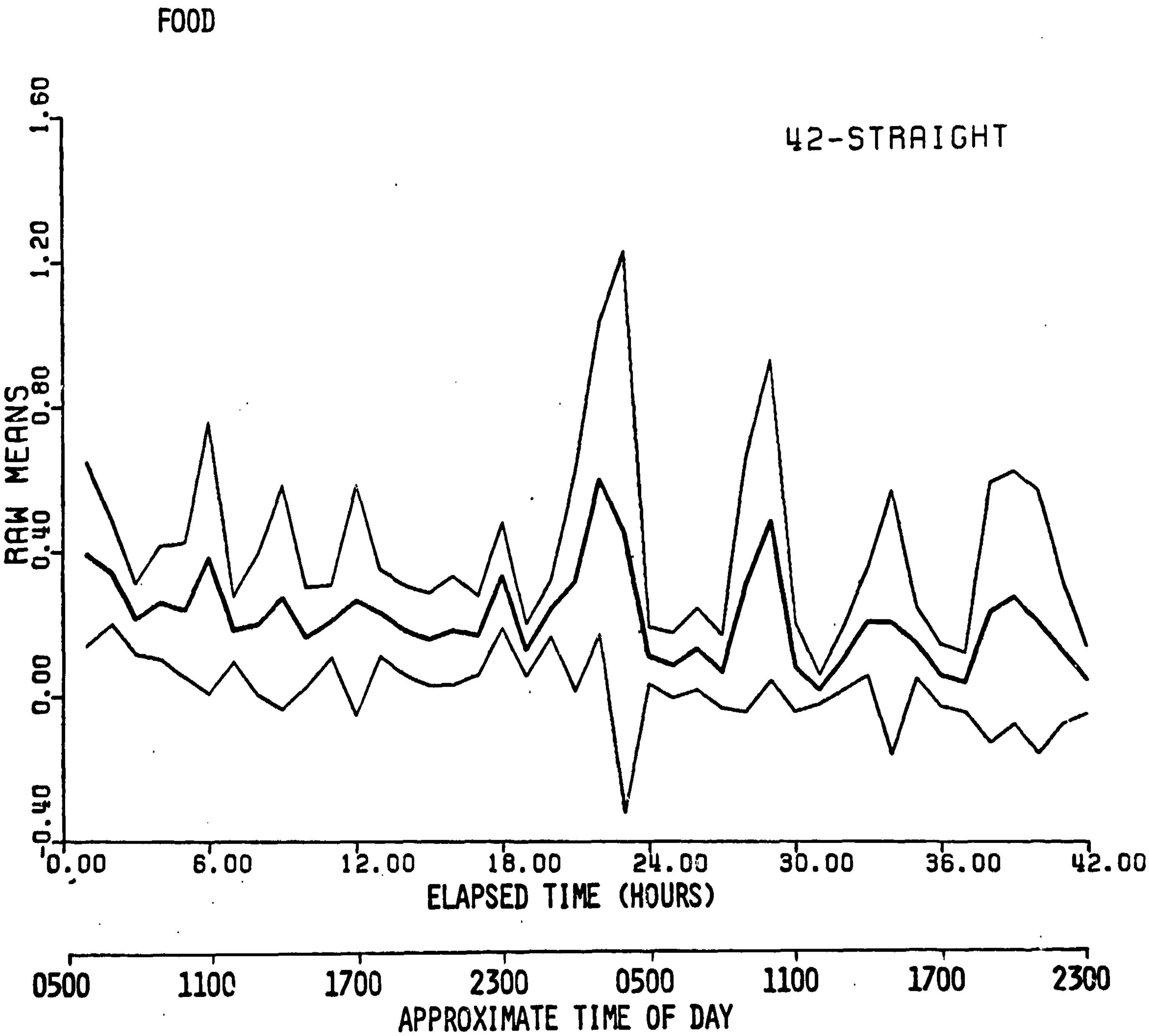



FIG. 13B Hourly means of food consumed for the 42-straight group. Also plotted are 95% confidence limits.

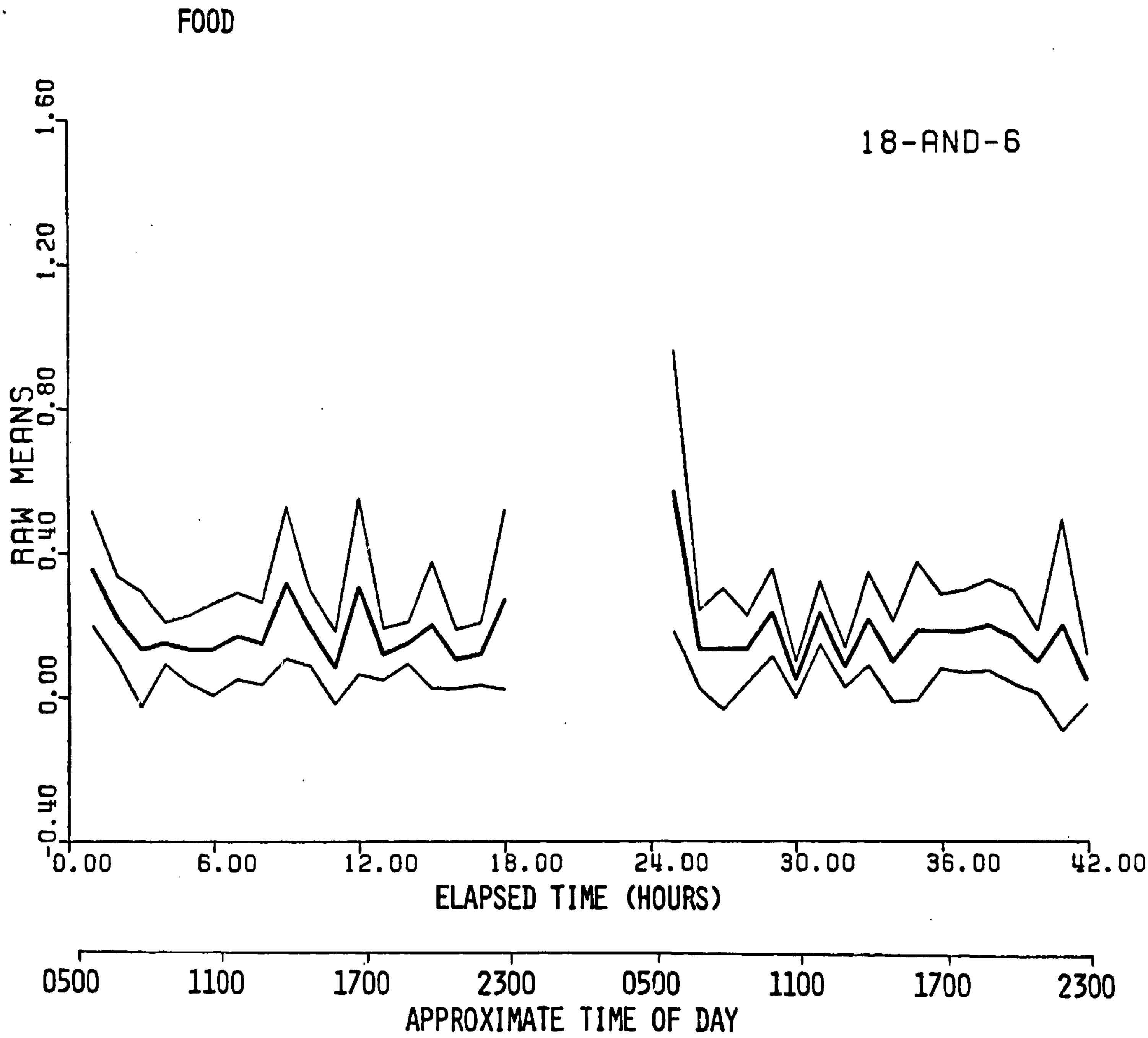



FIG. 13C Hourly means of food consumed for the 18-and-6 group. Also plotted are 95% confidence limits.

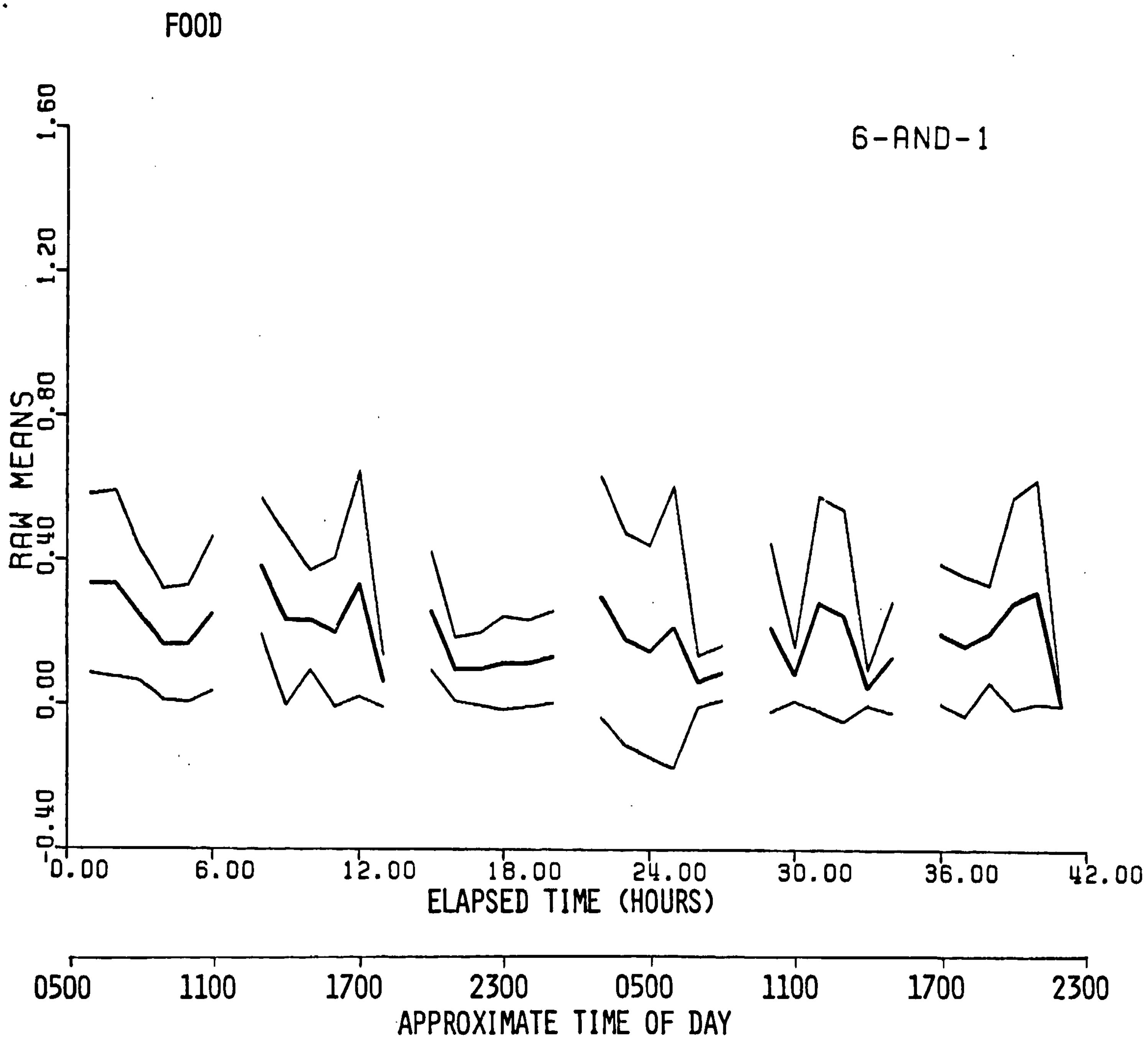



FIG. 13D Hourly means of food consumed for the 6-and-1 group. Also plotted are 95% confidence limits.

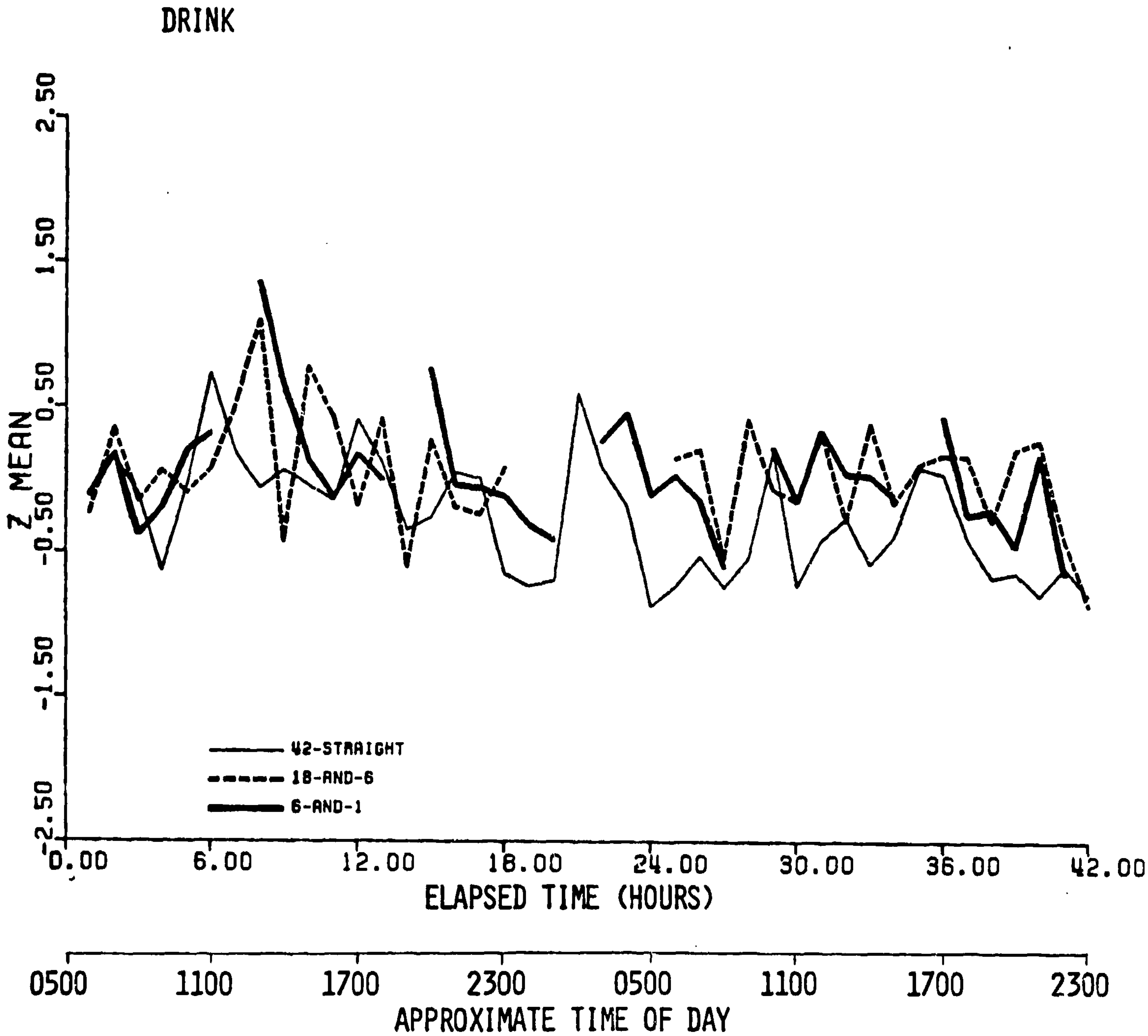



FIG. 14A Hourly means of normalized numbers of drinks consumed for the three experimental groups. Group data are plotted with the mean z-score of the first 6 hours set to the 0 level on the ordinate. Means were derived from z-scores for the entire data of each subject.

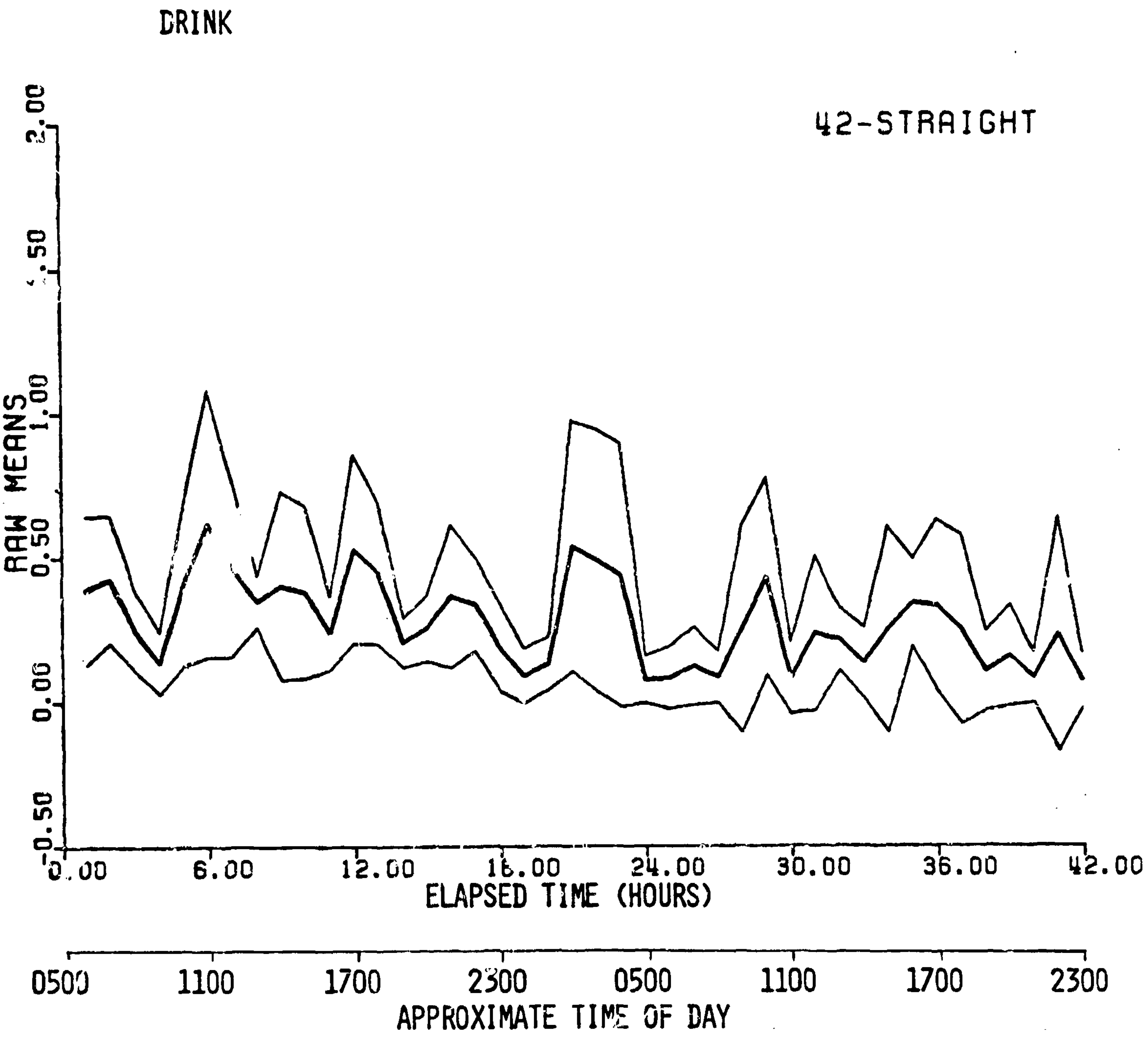



FIG. 14B Hourly means of numbers of drinks consumed for the 42-straight group. Also plotted are 95% confidence limits.

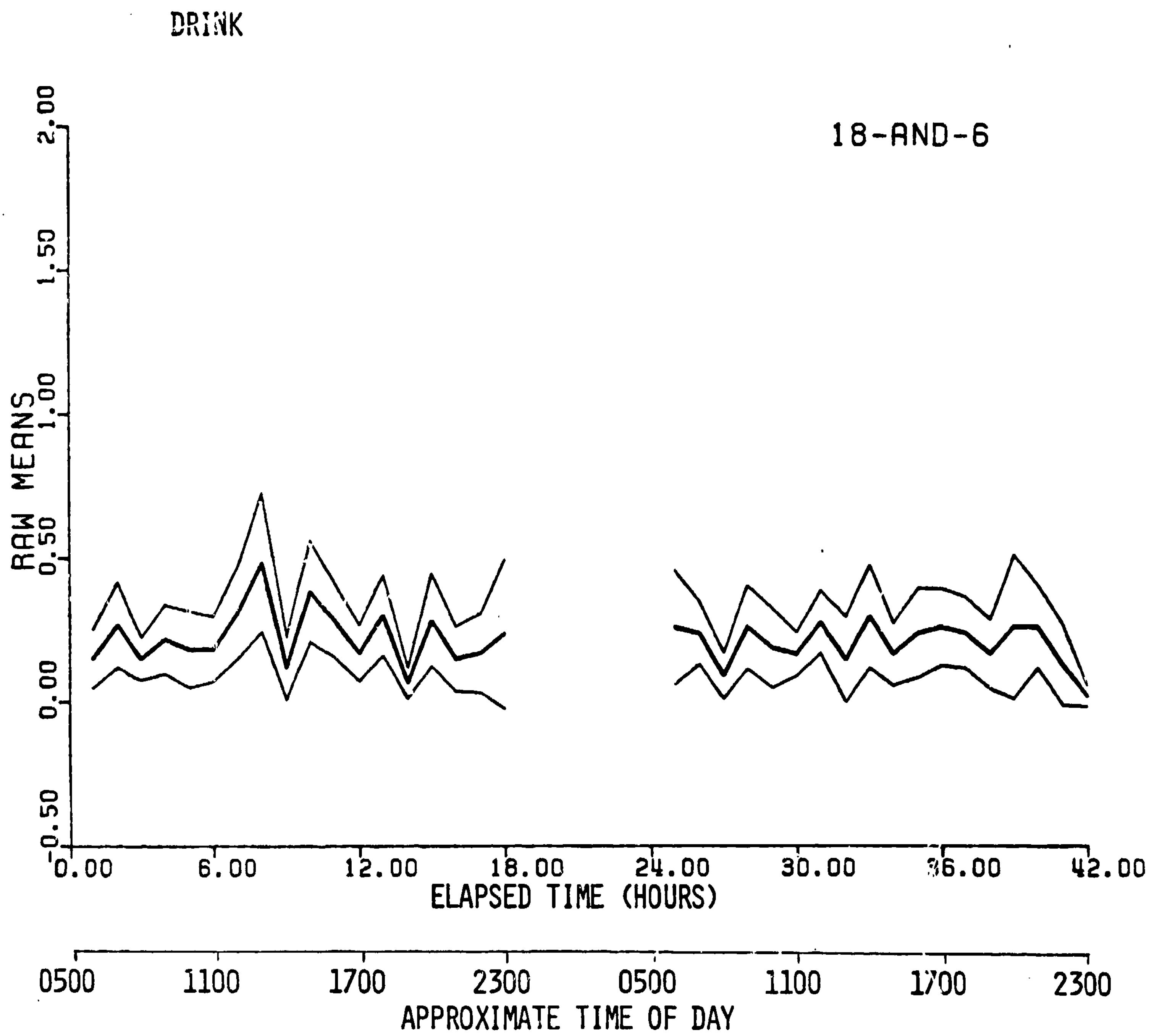



FIG. 14C Hourly means of numbers of drinks consumed for the 18-and-6 group. Also plotted are 95% confidence limits.

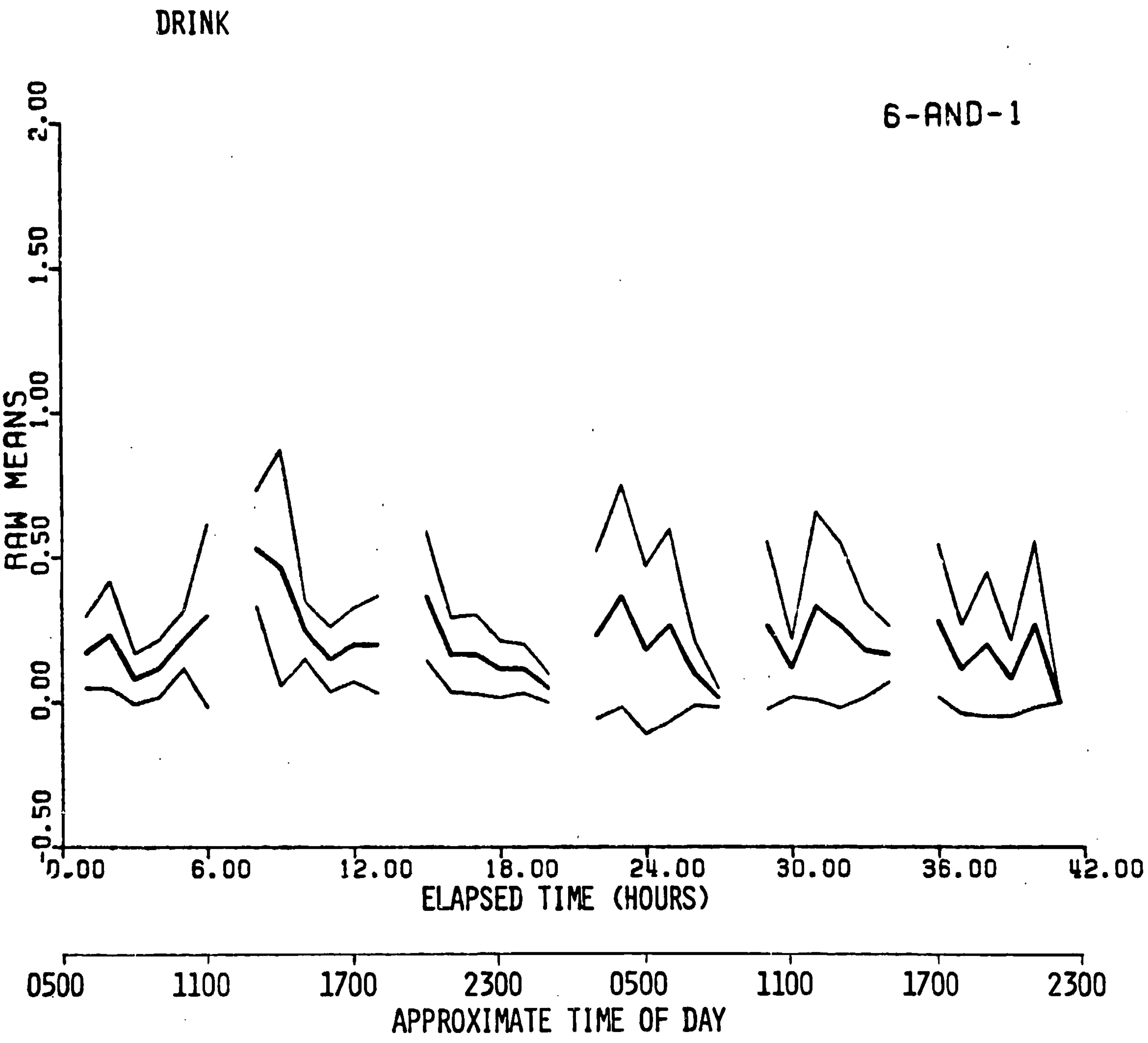



FIG. 14D Hourly means of numbers of drinks consumed for the 6-and-1 group. Also plotted are 95% confidence limits.

RESTROOM TRIPS

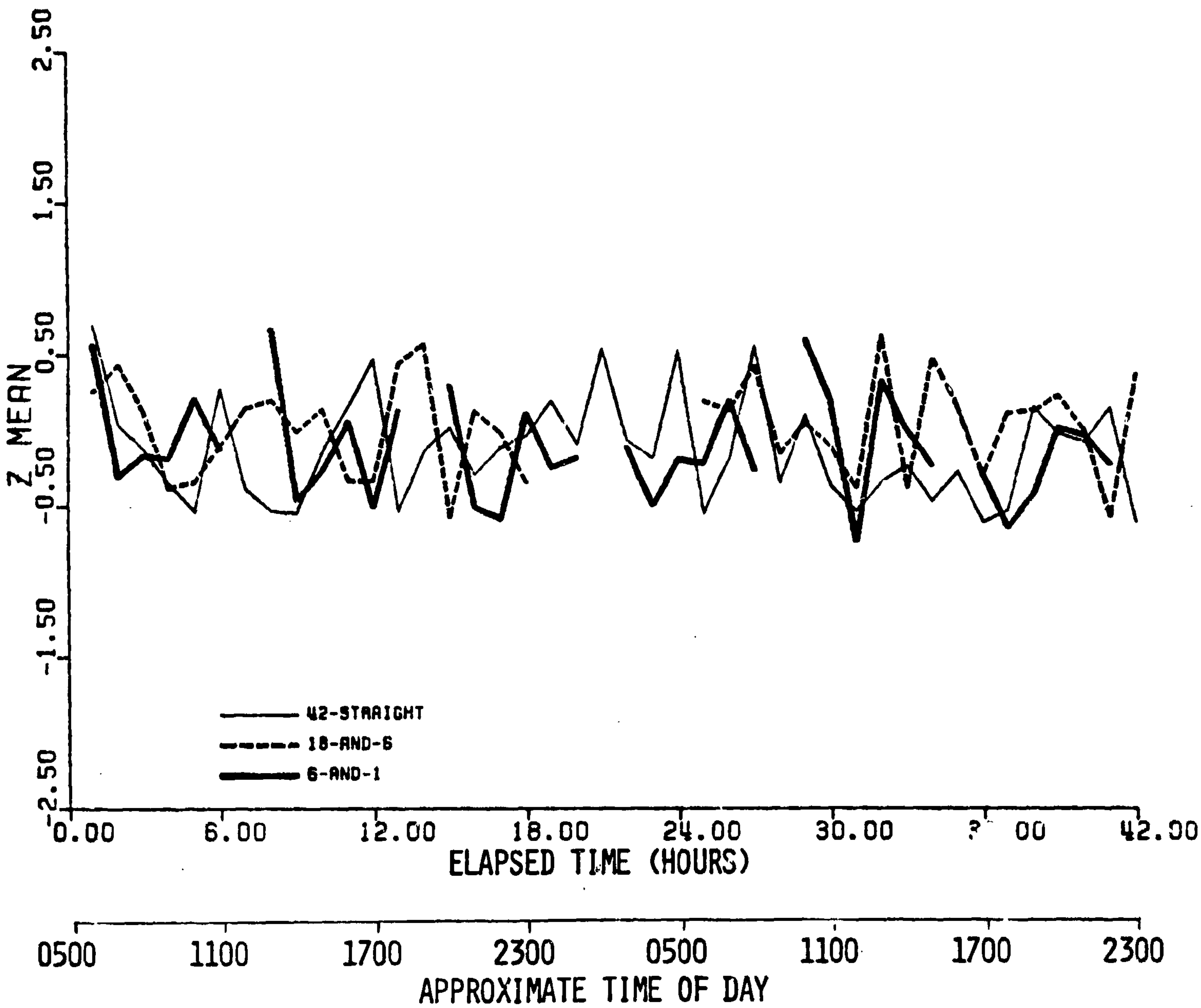



FIG. 15A Hourly means of normalized numbers of restroom trips taken for the three experimental groups. Group data are plotted with the mean z-score of the first 6 hours set to the 0 level on the ordinate. Means were derived from z-scores for the entire data of each subject.

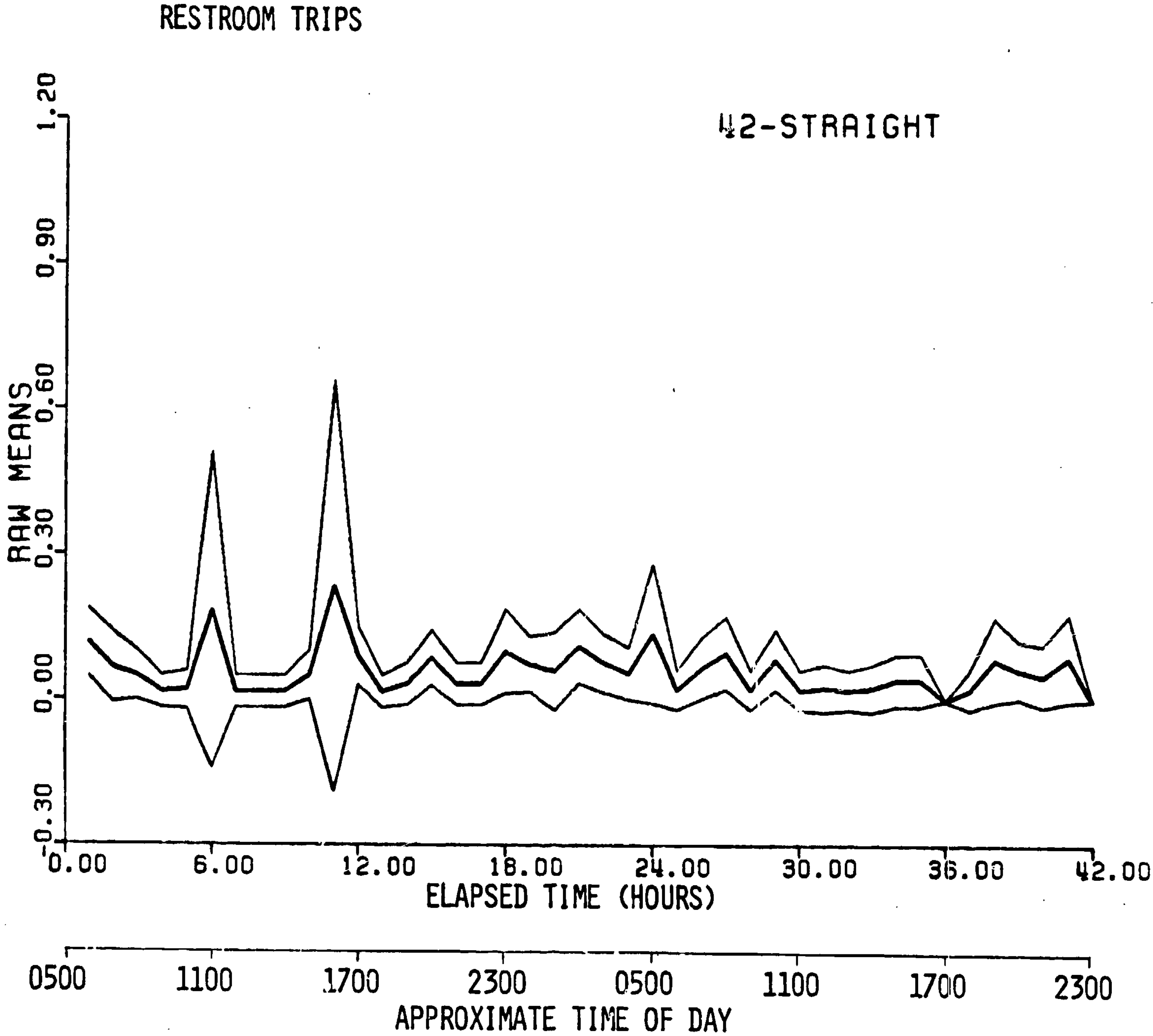



FIG. 15B Hourly means of numbers of restroom trips taken for the 42-straight group. Also plotted are 95% confidence limits.

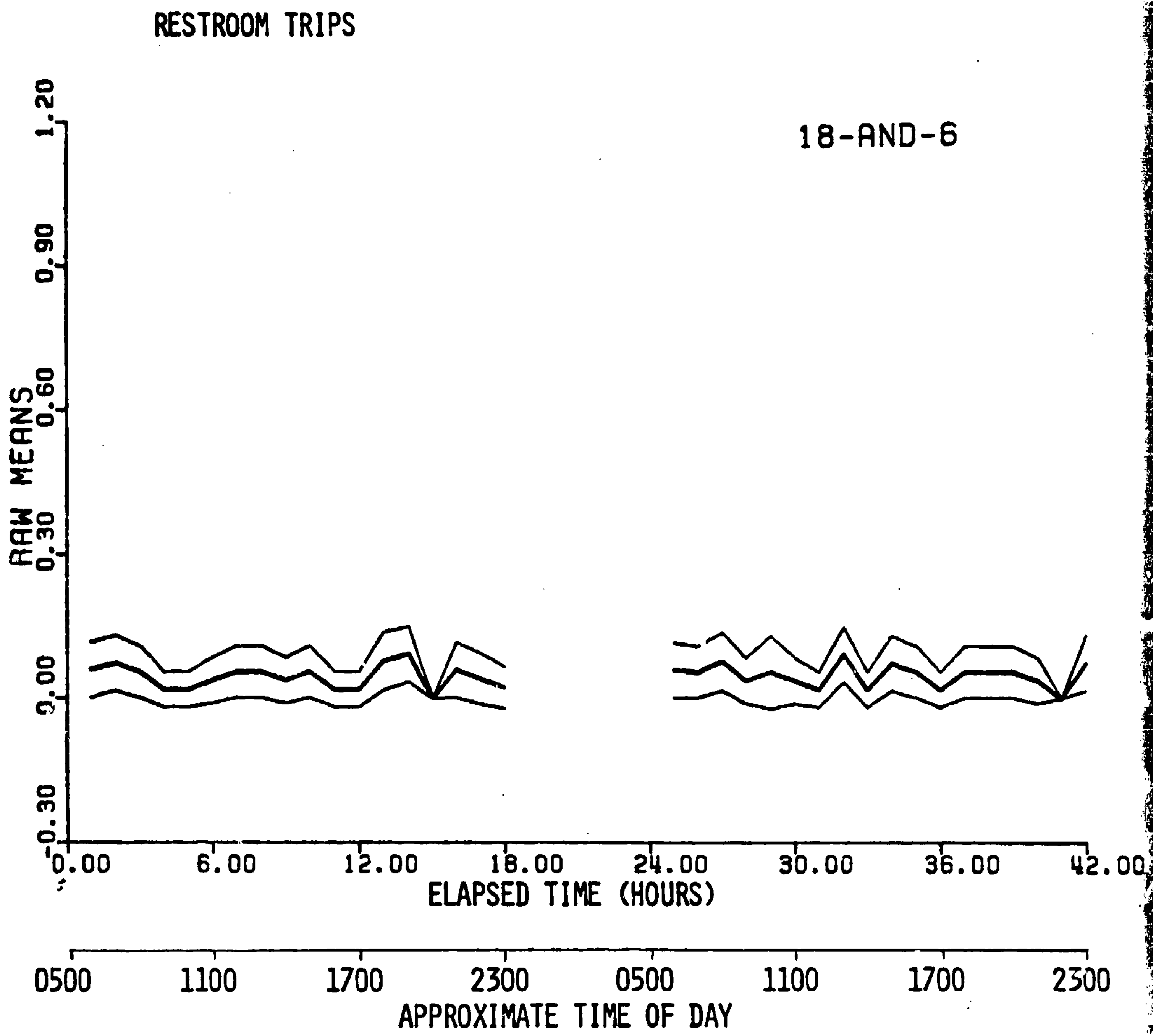



FIG. 15C Hourly means of numbers of restroom trips taken for the 18-and-6 group. Also plotted are 95% confidence limits.

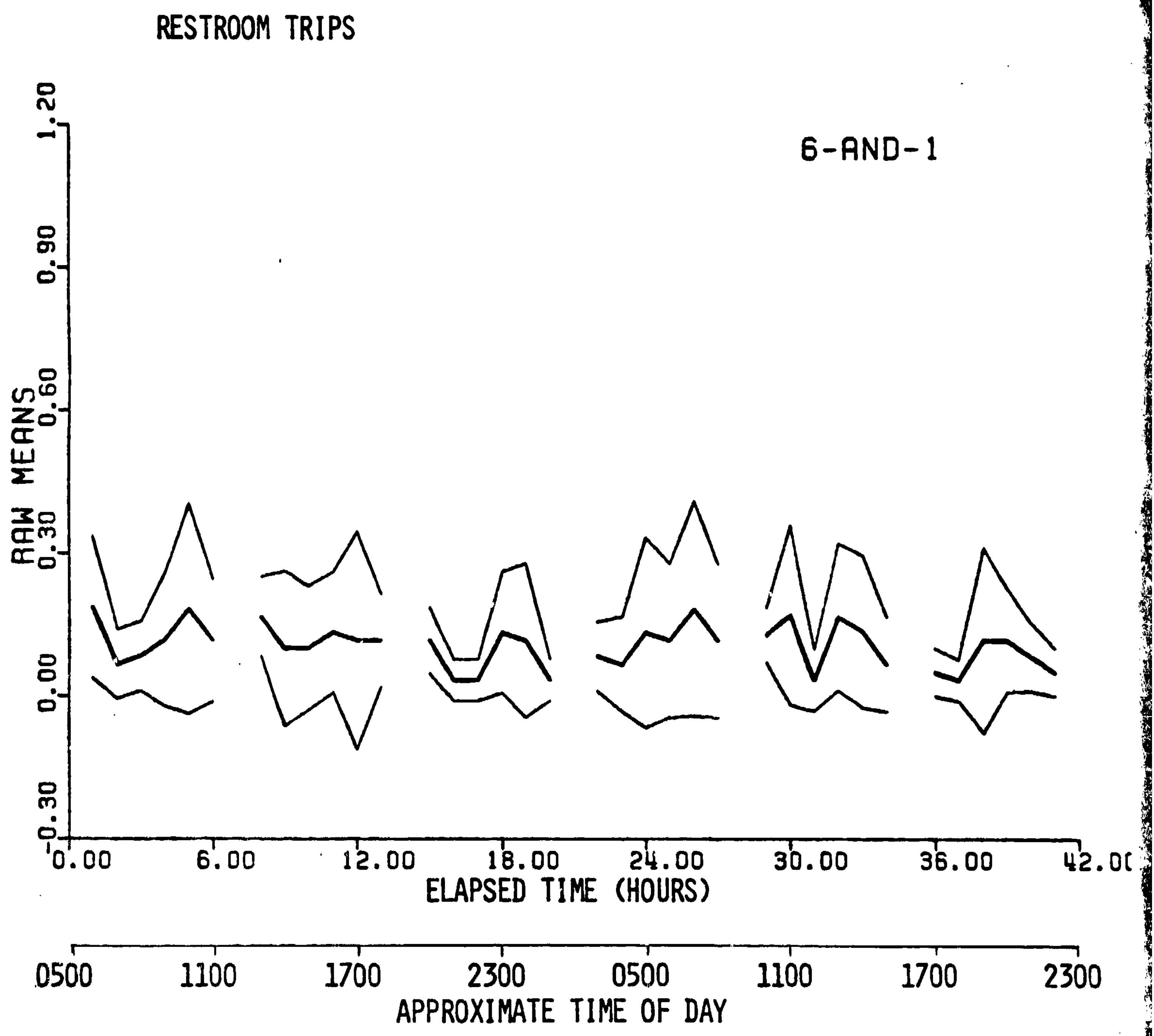



FIG. 15D Hourly means of numbers of restroom trips taken for the 6-and-1 group. Also plotted are 95% confidence limits.